PRODUCTION AND ECONOMIC EFFECTS OF DEVELOPING HEIFERS ON THREE DIFFERENT LEVELS OF STAIR-STEP NUTRITION PROGRAMS

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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May 2018

Major Subject: Animal Science

ABSTRACT

Links between nutrition and reproductive success in heifers are well established; however, achieving a high plane of nutrition is costly, and reproductive success remains uncertain, making heifer development both expensive and risky. Development could be optimized by creating nutritionally efficient strategies that manage plane of nutrition without negatively impacting reproductive success. At an average age of 340 d (209 kg) 85 heifers were randomly assigned to 1 of 3 treatments: high (H, $n = 29$), programmed to gain 0.92 kg/d, medium (M, $n = 28$), 0.45 kg/d and low (L, $n = 28$), 0 kg/d from d 0 to d 49 (P1). All heifers were then programmed to gain 1.36 kg/d from d 50 to d 90 (P2). Heifers were individually fed a common diet (42% cracked corn, 26% DDG, 26% alfalfa hay, and 6% molasses; 14.0% CP, 1.1 Mcal NEg/kg) at different levels to achieve programmed rates of gain. Weekly BW and blood samples were collected. Digestion was measured beginning on d 41 (P1) and on d 83 (P2). All heifers were synchronized beginning on d 90 using the Bee-Synch protocol for fixed-time AI on d 98, followed by 56 d exposure to bulls. Pregnancy rates were determined on d 154. Gain differed between treatments in P1 ($P < 0.01$); M- and L-fed heifers exceeded programmed gain by 0.16 and 0.37 kg/d respectively (H = 0.83, M = 0.61, L = 0.37 kg/d), and tended to differ ($P = 0.07$) in P2 (H = 1.31, M = 1.41, L = 1.37 kg/d). Digestion in P1 differed ($P = 0.01$) between heifers fed H (86.2% DM) and L (88.7% DM); no differences ($P = 0.23$) were observed in P2. Total ADG and input costs were different among treatments ($P < 0.01$). Cost of development for the M and L treatments were $10 and $23 less per heifer, respectively, than H ($95.35). Body weight and number pubertal on d 90 were not different ($P \geq 0.10$). Pregnancy rates on d 260 were not different ($P = 0.99$) being 97, 100, and 96% for H, M, and L, respectively. Developing heifers on a lower plane of nutrition decreased cost per pregnancy without apparent negative effects on reproductive success. The L strategy was the optimal development program based on cost per pregnancy; however, additional research is needed to confirm the effects on reproductive outcomes.

With various strategies being viable options in terms of successfully achieving pregnancy, it is often difficult to determine which is the best decision, economically, for a specific operation. A heuristic approach can easily be applied, subconsciously, to making managerial decisions of an operation, potentially leading to increased error in decision making. Therefore, a decision tool was developed comparing five different development programs. Programs were compared using net cost per pregnancy (CPP) to determine the optimal strategy, based on rational decisions, that would likely prove more consistent over time. A sensitivity analysis was conducted to evaluate the extent to which each variable accounted for impacted the CPP. Cost at weaning was observed as the most influential factor when selecting an optimal program, followed by other losses (related to death and mechanical loss), and yearling heifer price. Overall the tool proved successful at aiding in making a rational decision.

ACKNOWLEDGEMENTS

Completing this degree was one of the most trying, yet gratifying, accomplishments and I could not have done it without the guidance, encouragement, love and support of so many.

First and foremost, I thank my Lord and Savior, without Him none of this would have been possible. “Trust in the Lord with all your heart, and do not lean on your own understanding. In all your ways acknowledge him, and he will make straight your paths.” Proverbs 3:5-6.

To my husband, Garrett: words cannot begin to express how thankful I am for your constant support and encouragement. You always believed in me, usually far more than I believed in myself and always knew just what to say to keep me going. Thank you for loving me selflessly when it wasn’t easy and for encouraging me to pursue grad school as far back as our Sophomore year.

To my family; especially Dad, Mom, and Brent: thank you for encouraging me to always follow my passion for agriculture and allowing me to travel halfway across the country to pursue my educational dreams even though you didn’t quite understand my affinity for being covered in manure and rumen fluid. To say you set an example of what it meant to work hard is an understatement. I am forever grateful for the work ethic you instilled in me and your unwavering support; you have helped me achieve so much over the years.

To my mentors, Dr. Wickersham, Dr. Sawyer, Dr. Cardoso, and Dr. Anderson: thank you for allowing me the opportunity to further my education in beef cattle nutrition. You have each provided me with unique and invaluable wisdom that I will carry on into my career and future endeavors. I am extremely grateful to have you all as mentors. Dr. Wickersham: there is no way to thank you enough for all the opportunities you have provided me over the years or the guidance you have given me; you have made an impact that will last a lifetime. Dr. Sawyer: thank you for challenging me to be a better learner, you've taught me so much regarding real-life application and how not to take what I learn at face value, always asking "why?". Thank you for allowing me to carpool with you back and forth to McGregor and for all the entertaining stories along the way.

To the 017B crew, past (Levi, Jessie, Natasha, Myriah, Caleb, Shelby, Sarah, Amelia, Lauren, Courtney, and V) and present (Jessica, Nessie, Allison, Colton, and Lauren): I can't imagine a better group of people to have spent my time with down in the SSTC, let alone during midnight sampling and rumen evacs. Over the years you have all taught me so much while providing endless laughs and memories. Special thanks to Jessica ("Baber") who was tasked with training me as a student worker back in the day; thank you for your patience and friendship. I will always remember our times troubleshooting the bomb calorimeter on what seemed like a daily basis and fixing all the equipment Levi "broke" in an attempt to do lab work over the years.

To the student workers: Jordan, Jodi, and Natalie, thank you for all you did helping me complete my lab work. Jodi and Natalie thank you for volunteering to spend 3 days with me out at McGregor for sampling, especially Jodi for enduring our unique "camping" experience.

To the guys at the McGregor Research Center: thank you for always being more than willing to help and providing constant entertainment (Barton) while we worked. Jeremy, David, and Dakota thank you for taking such good care of my heifers and for all your help throughout the project.

To the Wickersham family: Tryon, Erin, Katherine, and Lydia, thank you for including Garrett and me in family events and activities; we have enjoyed your friendship and watching the girls grow up and look forward to seeing all of their great accomplishments in the future. Thank you for opening your home for annual grad student events as well, you have helped foster a sense of community and tradition among all of us in 017B.

Also, a special thank you to Dr. Cardoso and Jose for volunteering their time to AI my heifers and to Emma training me in running radioimmunoassays.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supported by a thesis committee consisting of Professors Tryon Wickersham (Advisor), Jason Sawyer (Co-Advisor), and Rodolfo Cardoso of the Department of Animal Science and Professor David Anderson of the Department of Agricultural Economics.

Funding Sources

There are no outside funding contributions to acknowledge related to the research and compilation of this document.

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CHAPTER I

INTRODUCTION AND REVIEW OF LITERATURE

Introduction

Developing heifers is a critical component to the sustainability of beef production, especially in the cow-calf sector. Overarching development goals are to produce heifers able to reach puberty and conceive early, sustain pregnancy, calve unassisted early in the season, and rebreed within 60 d postpartum, all for a low cost (Lardner et al., 2014). Traditionally the recommendation is to develop heifers to 60-65% of their mature weight (MW) prior to breeding at approximately 13-15 months of age. This recommendation, in theory, allows for one or more estrous cycles prior to the breeding season, as the first estrus is thought to be less fertile than subsequent cycles, and allows heifers to calve at 2 years of age and approximately 80% of their MW (Patterson et. al., 1992). Recent research demonstrates developing to a lesser percentage of MW has no effect on subsequent reproduction and decreases development costs (Funston and Deutscher, 2004; Martin et al., 2008; Lardner et al., 2014).

Obtaining quality replacement heifers is one of the major costs facing cow-calf producers. Whether they are obtained through developing young heifers currently within the herd or purchased from an outside source is a situational decision made by individual producers. Required replacement rate depends on a variety of factors including, but not limited to, cow age, cow death loss, and numbers of calves weaned (Rogers, 1972) and is vital to herd sustainability. Uniformity is one factor that affects the overall success of incoming females. Introducing a uniform group of heifers to the breeding herd that are all of known, similar age, weight, and maturity mitigates the total time and inputs invested in preparation for breeding as compared to collecting a diverse set of heifers. Uniform quality sets replacements up for success resulting in a condensed breeding season allowing them to calve earlier in comparison to the herd, which improves lifetime production potential (Lesmeister et al., 1973).

Fertility also plays a key role in the success of a replacement program. Attainment of puberty and conception are vital traits to consider when evaluating the successful introduction of heifers into a herd. Exogenous factors, such as synchronization protocols, successfully induced puberty in non-cycling heifers, potentially lead to an increase in reproductive success (Gonzalez-Padilla et al., 1975; Short et al., 1976; Patterson et al., 1990), further mitigating financial risks associated with development. Links between nutrition and reproductive success in heifers have been demonstrated (Day and Anderson, 1998; Gasser et al., 2006a); suggesting uniformity and fertility can be achieved more easily through the use of a successful development program.

Puberty

To become bred a heifer must first achieve reproductive maturity by the time of breeding. Attainment of puberty is used as an indicator of reproductive status. An animal is characterized as pubertal after first ovulation (Nogueira, 2004). For puberty to occur a series of physiological events must take place in the heifer progressing through the central nervous system, anterior pituitary gland, and finally to the ovary. The brain begins by collecting information regarding external and internal environments such as photoperiod, stress, and nutritional status which is integrated in the hypothalamus resulting in the release of GnRH among other neuroendricine signals (Schillo et al., 1992). Pulsatile release of GnRH causes the pulsatile release of the gonadotropin LH (Levine et al., 1982) which is the primary endocrine factor responsible for regulating the onset of puberty in heifers (Kinder et al., 1994). The last 2 to 3 mo before the onset of puberty, there is a gradual decrease in sensitivity of the hypothalamus to estradiol negative feedback resulting in an increase in GnRH and LH pulse frequency. Luteinizing hormone causes growth of antral follicles resulting in enhanced estradiol secretion (Day et al., 1987; Evans et al., 1994). A peak in estradiol secretion by the dominant follicle stimulates a large preovulatory surge of LH, inducing ovulation (Schillo et al., 1992). Ovulation is often followed by one short estrous cycle and the onset of normal cycles thereafter (Day et al., 1987).

Timing of puberty

It is generally recommended that heifers attain puberty at least 2-3 months prior to the breeding season for optimal pregnancy rates as the first cycle in heifers is said to be less fertile than subsequent cycles. Byerley et al. (1987) reported heifers bred on third estrus had a 21% greater pregnancy rate than heifers bred on pubertal estrus. It is desirable for heifers to be bred earlier in the breeding season allowing heifers time to recondition for rebreeding and their calves adequate time for growth prior to weaning (Funston, 2004). Heifers calving earlier in the calving season had higher lifetime production potential overall (Lesmeister et al., 1973).

Breed and genetics play a key role in age of maturity, for example; heifers bred for greater mature size tend to reach puberty at a later age and heavier weight than those of moderate size (Laster et al., 1972). While the physiological mechanisms for the onset of puberty are very similar, *Bos indicus* cattle tend to reach puberty at a later age than *Bos taurus*. Puberty is a highly heritable trait and genetic selection for more precocious heifers, in terms of reproductive maturity, growth, fat deposition etc., has not occurred as extensively in the *Bos indicus* breeds and thus a delay in maturation is often observed (Nogueira, 2004). Sacco et al. (1987) reported an average difference of nearly 150 d between age at puberty for Angus and Brahman heifers. In contrast, Angus Brahman crosses were shown to reach puberty at a similar age as straight-bred Angus with an average of only a 7 d difference, in a controlled setting (Sacco et al., 1987).

Diet composition may play a specific role in age at puberty as well. Precocious puberty in heifers, which will be discussed in depth in a later section, has been induced through the use of a high-concentrate diet (Day and Anderson, 1998; Gasser et al., 2006a,d). Diets with high-concentrate, low-fiber levels increase propionate production in ruminants (Bauman et al., 1971; Ciccioli et al., 2005) with ruminal propionate concentrations being directly related to intake of rapidly fermentable carbohydrates (Krause et al., 2003). Propionate is the only VFA that makes a net contribution to glucose synthesis; increased glucose concentrations lead to increased insulin response. In the presence of insulin, substrates from digestion are taken up as energy and stored as fat (Zieba et al., 2005). Leptin; an adipose-based hormone, is positively correlated with body fat mass and plays a passive role in timing of the onset of puberty, signaling nutritional status (Amstalden et al., 2000; Maciel et al., 2004; Zieba et al., 2005; Cardoso et al., 2014).

Precocious puberty

Spontaneous puberty has been observed to occur before 10 months of age (Wherman et al., 1996) which is considered part of the static phase of development in heifers (Gasser, 2013). Data reported by Day and Anderson (1998) showed the incidence of precocious puberty (puberty ≤ 300 d) was increased by a development program of early weaning heifers and feeding a high-concentrate diet. Gasser et al. (2006a,d) supported their findings and reported subsequent estrous cycles were observed to continue after precocious puberty as well. With a significant amount of pressure placed on the attainment of puberty in sufficient time prior to breeding, precocious puberty can be studied to better understand the window of opportunity for nutritional programming to optimally time puberty (Cardoso et al., 2014). A series of experiments were designed to determine the mechanisms by which precocious puberty occurs in early weaned, high-concentrate fed heifers. It was concluded that a decrease in estradiol’s negative feedback of LH leads to greater frequency of LH pulses leading to precocious puberty at lighter BW (Gasser et al. 2006a,b,c,d).

Negative effects of breeding during precocious puberty include: increased likelihood and degree of dystocia as age at first calving decreases (Short et al., 1990), and increased length of postpartum interval (Patterson et al., 1992). Developing heifers to achieve precocious puberty is not a viable management tool for production purposes; however, precocious puberty clearly demonstrates the impact nutrition has on obtaining reproductive maturity in heifers and can be used to improve heifer development programs.

Estrus synchronization

Estrus synchronization alters the reproductive cycle through the administration of hormones at strategic times to better manage breeding, especially when using AI. Benefits of synchronization include: creating a more uniform calf crop by shortening breeding/calving seasons, reducing labor if utilizing AI including reduction, and potentially elimination, of the need to check heats and shortening the breeding season. The bovine estrous cycle lasts 21 d, a synchronized animal should have 3 opportunities to become bred within a 45 d breeding season, if utilizing AI at least one time. Ideally, an estrous synchronization program would result in a fertile, tightly synchronized estrus response from a high percentage of treated females (Odde, 1990). Methods of evaluating synchronization protocols include estrous response, the proportion of those treated showing estrus, conception rate to AI, pregnancy rate to AI, and pregnancy rate at times throughout the breeding season (Odde, 1990; Mallory et al., 2010). Degree of synchrony is especially important when evaluating a protocol to be utilized for fixed-time AI (TAI) when estrus detection is not performed before breeding.

Just as breed type has an effect on age at puberty (Sacco et al. 1987), it also plays a role in determining the success of an AI protocol. In general, protocols are designed to allow for AI after estrus has been detected or at the time of induced ovulation if utilizing TAI. *Bos indicus* have shorter durations of estrus compared to *Bos taurus* breeds and a TAI protocol is one method that can be used to increase service rates especially in cross-bred heifers (Carvalho et al., 2008). *Bos indicus* do not have as high of pregnancy rates to some synchronization protocols as *Bos taurus* cattle. Williams et. al. (2012) reported TAI pregnancy rates with traditional 5 d CO-Synch +CIDR (controlled internal drug release, progesterone) are consistently <40% in *Bos indicus*-influenced cows as opposed to *Bos taurus* which frequently exceed 60% TAI pregnancy rates. This can be attributed to the differences in concentration of and sensitivity to reproductive hormones between *Bos indicus* and *Bos taurus* such as LH, estradiol, and progesterone (Yelich and Bridges, 2012). Based on the theory that *Bos indicus* influenced cattle are more sensitive to progesterone, Dr. Gary Williams at the Texas A&M AgriLife Research Station in Beeville, TX developed the modified 5 d Co-Synch + CIDR TAI protocol ("Bee-Synch") which includes a dose of PG at CIDR insertion eliminating any existing CL. Accordingly, this results in the only source of progesterone being the CIDR device. Following this protocol proved successful in *Bos indicus* influenced cows with a pregnancy rate to TAI of greater than 50% (Williams et al., 2012; Scarpa et al., 2017). Williams et al. (2012) reported *Bos indicus* influenced cows bred using the standard 5 d CIDR protocol had a pregnancy rate of 35.7% as opposed to 52.4% with the modified Bee-Synch, comparable to *Bos taurus* cattle when utilizing the 5 d CO-Synch + CIDR TAI protocol (58.1%; Whittier et al., 2013).

Summary of reproductive physiology

For a heifer to breed she must first be cycling, ideally completing one or more estrous cycles prior to breeding, setting her up for the best pregnancy success rate. Estrous synchronization can be used to help improve breeding outcomes; however, a sound foundation of maturity is the most ideal management goal. Nutrition, specifically increasing energy stores through the use of high-concentrate diets over extended periods of time, has been shown to induce precocious puberty in heifers and can be more appropriately adapted and utilized to create more innovative and successful heifer development programs.

Bioenergetics

In 1915, Armsby and Fries were among the first to describe the flow of energy in cattle. Energy intake is defined as gross energy (GE; Figure A1) which is the total heat of combustion of any specific diet; however, GE alone is not an adequate measure of energy available for utilization by the animal. Throughout digestion and metabolism energy is lost in the feces, gas, and urine or as heat. Energy is also utilized for production events such as lactation, fetal growth, or retained in tissues. Accordingly, it was necessary to describe energy utilization as a system to accurately partition energy losses. Digestible energy (DE) is defined as GE less fecal energy (FE), DE = GE – FE, with FE generally accounting for the largest loss of energy. Metabolizable energy (ME) is DE less gaseous energy (GASE) and urine energy (UE), ME = DE – (GASE + UE). Gaseous energy is mainly comprised of methane (CH_4) resulting from fermentation and released via eructation or respiration. Retained energy (RE) also referred to as net energy (NE), is the most accurate representation of the energy available to the animal for biosynthetic use and is calculated as ME less heat production (HE) or NE = GE – (FE + GASE + UE + HE). The heat that is lost fluctuates with a variety of factors including diet, animal size, breed type and activity level (Baker et al., 1991).

Metabolizable energy utilization

It was long accepted that NE could be classified as one single value until 1963 when a more complete system was proposed that separated NE into two terms (Lofgreen, 1963 a,b). This work was later revised and published (Lofgreen and Garrett, 1968) to become what is now referred to as the California NE System (CNES). This system assigns NE values for maintenance, $NE_{m,}$ as well as gain, NE_g, to better represent and describe energy retention. The goal behind developing the system was to improve accuracy of ration formulation and prediction of animal performance.

Net energy for maintenance is equivalent to fasting heat production (FHP) which estimates the basal metabolic rate, the energy required to maintain vital functions, and heat of activity (Baker et al., 1991). In determining NE values, NE_m is the amount at which the animal neither gains nor loses energy as opposed to NE_g which represents the amount of energy required for an additional unit of gain above maintenance. The change between FHP and energy equilibrium (RE= 0; Figure A2) is the partial efficiency of ME utilization for maintenance (k_m). Energy retention above maintenance is represented by $k_{r,}$ the partial efficiency of ME utilization in excess of maintenance requirements, which can be utilized for body tissue, lactation, or tissues of the conceptus. In the case of developing heifers; however, k_r is allocated strictly to the use of gain.

Generally speaking, maintenance and lactation are both more energetically efficient processes than gain (Garrett and Johnson, 1983). The difference in efficiency can be accounted for by the differences in heat increments associated with meeting maintenance requirements and that of growth/product formation (Ferrell and Oltejen, 2008). Increased intake also results in increased organ weight, specifically the liver. With the liver being responsible for intermediary metabolism it is expected that changes in feed intake would effect the liver size and metabolic activity, thus changing the total amount of heat lost (Garrett and Johnson, 1983; Drouillard et al., 1991; Yambayamba et al., 1996). That being said, it is also important to note that maintenance requirements are dynamic and influenced by nutritional history and current energy intake (Freetly and Nienaber, 1998; Ferrell and Oltjen, 2008).

Growth

A unique component to managing heifers as opposed to mature cows is their additional requirements for growth. For growth to occur, a heifer must consume energy in excess of her maintenance requirement. In general, the NE_m can be determined for cattle using the equation $NE_m = 0.077EBW^{0.75}$ (NASEM, 2016). However, as previously mentioned, energy requirements for maintenance vary with BW, breed, sex, age, etc. Therefore, a more accurate representation of NE_m requirements may come from an equation which includes empirical adjustment for factors such as these (Ferrell and Oltgen, 2008). For example, the NASEM (2016) recommends using an adjustment for previous nutrition (COMP) where $COMP = 0.8 + (BCS-1) \times 0.05$, in instances where previous nutrition varied such as in the case of compensatory gain which will be discussed in a later section. Maintenance requirements must be met before growth can occur. Generally speaking, growth is an integrated process resulting from cell response to endocrine status and nutrient availability, during normal development muscle exhibits the greatest growth rate, initially, followed by fat tissue (Hornick et al., 2000). With fat tissue playing a potentially important role in the onset of puberty in heifers (Almstaden et al., 2000; Maciel et al., 2004), it is important to ensure nutritional requirements are satisfied.

Emphasis should be placed on the need for replacement heifers to be managed separate from the mature cow-herd as their nutritional demands, size, and age do not allow them to compete with the rest of the herd (Bolze and Corah, 1993). Depending on variation in weaning weight, heifers may benefit from being sorted at weaning into light and heavy groups and fed separately to meet targeted breeding weights. Varner et al. (1977) demonstrated when fed separately, sorted light-weight heifers were able to gain 23 kg more in a given development period than their unsorted light-weight counterparts fed in a combined group with heavy-weight heifers. Cost of feeding separately was only \$0.03 $\times$ hd^{-1} $\times$ d^{-1} more than managing as a large group and resulted in a 19% increase in conception rate between the lighter groups with a 15% increase in conception rate overall compared to the unsorted herd.

Restrictive Feeding

Rising feed costs and decreasing land availability has prompted producers to seek alternative methods of heifer development to reduce expenses. It is traditionally recommended for developing heifers to have a targeted ADG from weaning to breeding of 0.45-0.68 kg/d with a target breeding weight of 60-65% MW (Bolz and Corah, 1993). Recent research has since suggested traditional approaches should be reevaluated to better optimize profits and sustainability as there is opportunity to reduce feed costs by altering the rate and timing of gain (Funston et al., 2007). One method to consider is feeding in confinement as opposed to grazing. A more intensified system comes with some barriers to entry such as the procurement, processing and delivery of feed ingredients which must be done in a cost effective way. For a confinement system to be a reasonable alternative, it must be more cost efficient or profitable than grazing alone. One potential method to decrease costs is to decrease heifer maintenance requirements.

Freetly and Nienaber (1998) showed that mature, dry, cows on a limit-fed diet were able to better utilize energy and nutrients as opposed to their maintenance fed counterparts. In their study the cows were fed in two 112 d phases with treated cows being fed at 35% below maintenance (phase 1) followed by a realimentation of 135% maintenance level (phase 2) and control animals being fed at continuous maintenance level for the full 224 d. Limit-fed cows reached a new, lower maintenance requirement by the end of the feeding period. Efficiency levels were greater in limit-fed cows in terms of RE, nitrogen retention, and BW as well as having lower heat production. Efficiency is defined as net retained energy divided by intake energy; with intake energy being constant in this study efficiency is simply retained energy. The cumulative efficiency was negative in phase 1 for treated cows; however, efficiency decreased in a quadratic manner and did not differ from zero by the end of restriction (d 112). The data suggest the efficiency with which they maintained energy was beginning to increase by the end of restriction and therefore with lower maintenance requirements they were better able to utilize the excess energy acquired in phase 2. With no detrimental effects noted to overall energy metabolism/performance the use of limit feeding should be considered a reasonable method to decrease total input costs of development.

Effects of compensatory gain

Compensatory gain is a familiar concept to most cattle producers and can be explained as a faster than normal rate of gain observed after return to adequate nutrient levels following a time of restriction or low plane of nutrition either due to environmental stress or a planned nutritional strategy (NASEM, 2016). In theory this concept can be used to decrease overall feed costs by restricting intake levels for an extended period of time and compensating for that loss in potential gain after realimentation. While some of that gain can be equated to increased fill due to an increase in overall intake, the explanation for this phenomenon is often generalized as an increase in feed efficiency. As previously mentioned, maintenance requirements are able to be manipulated by varying the available plane of nutrition resulting in an apparent increase of efficiency (Freetly and Nienabar, 1998). With NE_m being equivalent to FHP, which is predominantly associated with metabolic activity of visceral organs, it is important to note the effect organ mass has on energy requirements.

Energy expenditure by visceral organs, such as the gastrointestinal tract (GIT), liver, and heart comprise a major proportion of basal energy expenditure (Ferrell and Jenkins, 1985) with metabolic activity of the liver and GIT accounting for nearly 50% of the total energy expenditure in ruminants (Ferrell, 1988). Research has been conducted to determine the effects altered metabolic rate and size of visceral organs has on energy requirements (Ferrell and Jenkins, 1985; Koong et al., 1985; Burrin et al., 1990; Yambayamba et al., 1996). Burrin et al. (1990) fed wether lambs at an *ad libitum* or restricted (maintenance) level for a 21-d period observing the change in visceral organ mass (VOM) at day 0, 7, 14, and 21. Over the 21-d period the relative liver, stomach and small intestine weights were increased in the *ad libitum* lambs and decreased in those fed at maintenance. The liver was quickly impacted, having the greatest decrease in overall weight within the first 7 d for the maintenance fed lambs. By day 21 the liver weights of maintenance lambs were 52% of that of the *ad libtum* fed lambs which constituted the greatest decrease in overall VOM. These findings are consistent with previous research (Ferrell and Jenkins, 1985; Koong et al., 1985; Yambayamba et al., 1996) supporting the idea that VOM, especially of the liver and gastrointestinal tract, are influenced by plane of nutrition and highly related to FHP and a decrease in overall metabolic activity.

There is much support in previous research for the apparent decrease in maintenance following a period of restriction; however, the response is variable (Drouillard et al., 1991; Hornick et al., 1998). This variation may be explained by the extent of physiological changes that occur in response to restricted energy/protein intake. During refeeding, insulin secretion is increased while plasma GH concentrations remain high which likely allows more nutrients to be partitioned for growth processes (Hornick et al., 2000). The length of time an animal shows compensatory gain after realimentation is not well defined; however, Hornick et al. (2000) summarized (Figure A3) the change in growth rate for 120 d after refeeding. Compensatory growth rates in cattle moderately restricted for growth are cubic in nature; ADG increases for the first 30 d of realimentation and is maintained for another 30 d prior to slowly decreasing to reach a stabilized rate after approximately 4 mo of refeeding. Literature reviewed by Hornick et al. (2000), focused on moderate restriction; Drouillard et al. (1990) suggested compensatory growth is influenced more by differences in restriction severity than duration of restriction, therefore the figure may not accurately represent all compensatory gain patterns equally.

Digestion

Diet intake and digestion is affected by multiple factors including feed type, animal, and the feeding situation (Mertens, 1987). With digestion directly affecting nutrient supply to the animal it is important to understand digestion kinetics and how to estimate the site and extent of nutrient digestion in the GI tract. Nutrient types vary in the rate and extent to which they are digested in the rumen and digestive tract. In the reticulorumen digestion of feed is, in part, determined by microbial activity and digesta passage rate. Rate of digestion, kd, represents how quickly feed disappears while rate of passage, kp, is the rate at which digesta moves out of the reticulorumen. Ruminal digestion = kd/(kd+kp). Feeds are considered to have a potentially digestible and an indigestible fraction with disappearance of the indigestible fraction only occurring by passage (Owens and Goetsch, 1986); passage rate is directly related to extent of digestion. As passage rate decreases it allows more time for bacterial attachment (Owens and Goetsch, 1986) and, in turn, extent of digestion; the degree to which nutrients are made available to the animal.

Ruminal fermentation is a unique process to ruminants as they are able to take advantage of by-products as opposed to monogastric or hind-gut fermenters. Fermentation in the rumen accounts for 60 to 75% of DE and as much as 90% of carbohydrate digestion (Sutton, 1979). Carbohydrates are subjected to fermentation by microbes in the rumen with one of the main end products being VFA (a source of energy); acetate, propionate and butyrate. Microbial crude protein (MCP) is also produced, potentially improving protein quality. Post ruminal digestion and absorption of nutrients is also affected by overall passage rate. While structures exist in the small intestines to aid in these processes, only so many nutrients can be absorbed if passage rate is too high. To take advantage of available nutrients it may be reasonable to modify passage rate of the diet to increase overall extent of digestion.

With digestion being a time-dependent process it is important to understand factors that can influence passage rate and increase overall extent of diet digestion. When intake level is limited, passage is relatively constant which removes most of the variability associated with the animal leaving the extent of digestion mainly up to the rate of digestion characterized by the diet (Mertens, 1987). Mertens (1983) used this same solution to mathematically model/explain the decrease in digestion observed when passage rate increases due to increased levels of feed intake. With this in mind, it can be hypothesized that the reverse is true, if intake level is restricted an increase in digestion will be observed compared to those fed at a higher level, due to a decreased k_p. This concept can be used when considering a limit-fed heifer development program as the diet nutrients can be digested and absorbed more efficiently due to decreased k_p.

Summary of nutrition overview

Heifers have an additional energy requirement for growth as opposed to managing mature cows. With growth being a less energetically efficient process than maintenance and lactation, improving overall feed efficiency of heifers in development systems is one strategy to reduce production inputs. Limit feeding has been shown to lower maintenance requirements as a proportion of nutrient utilization allowing for more nutrients to be partitioned toward gain especially if followed by a period of realimentation, taking advantage of potential compensatory growth.

Target body weight

Target BW principle is based on the idea that puberty can be expected to occur at a genetically predetermined size for an individual animal and maximum pregnancy rates can only be obtained once these end points are reached (Patterson et al., 1992). Target BW estimates for *Bos taurus* heifers are 60% of MW (Patterson et al., 1992) and 65% MW for *Bos indicus* breed types (Patterson et al., 1991). Funston and Deutscher (2004) developed *Bos taurus* heifers to either 55 or 60% MW and reported no difference in pregnancy rates and observed an increased number of heifers cycling before breeding in the 55% group suggesting no effect on reproductive performance. These results were supported by additional research that observed similar pregnancy rates when Angus heifers were developed to 55% MW compared to a more traditional 62% MW (Lardner et al., 2014). Martin et al. (2008) reported no difference among Angus heifers developed to 50, as opposed to 55%, MW. Interestingly, Greer et al. (1983) speculated that it is difficult to make an argument for absolute weight being a variable that affects the occurrence and timing of first estrus. With weight and first estrus both being physiological responses that are influenced by a set of the same basic elements, it is reasonable to think they are associated with one another but do not exhibit a cause and effect relationship. As a basic rule of thumb, the target BW concept is still practical as a method to ensure relatively high pregnancy rates but is not necessary. It must be understood that a wide array of genetic and environmental variables can impact pubertal development, (Patterson et al., 2000), and developing to lighter weights can decrease costs without negatively impacting reproduction (Funston and Deutscher, 2004).

Stair-step development strategies

Links between nutrition and reproductive success in heifers have been demonstrated (Day and Anderson, 1998; Gasser et al., 2006a); however, achieving a high plane of nutrition is costly, and reproductive success remains uncertain, making heifer development expensive and risky. Development could be optimized by using nutritionally efficient strategies to manage plane of nutrition without negatively impacting reproduction. One management strategy that has been successful in reducing cost of development is a stair-step approach. Stair-step development strategies were first introduced in the dairy industry when Park et al. (1987) designed an experiment to characterize compensatory growth patterns and improve growth efficiency and lactation potential in dairy cattle through the use of a high-fiber low-quality diet alternated with a high-energy, high-protein diet. Heifers were fed in a 5-2-5-2 mo schedule being fed 85% (5 mo; low quality diet) or 140% (2 mo; high-quality diet) NRC requirements. It was observed that the stair-step heifers lagged in weight gain compared to the control group during the restriction phase but were able to make-up that lag in the realimentation periods with the test group gaining a total of 25 kg more than the control group, on average. This method was interpreted as a simple and cost-effective method for raising dairy heifers.

Research conducted in beef cattle using similar methods to Park et al. (1987) has yielded similar results (Grings et al., 1999; Cardoso et al., 2014). The ability to be pubertal at time of breeding is important to reproductive success, thus a cost-effective development program must also not negatively impact reproduction. Using *Bos indicus* influenced heifers, Cardoso et al. (2014) investigated two different stair-step regimens (SS-1, SS-2) compared to a high (HC) and low (LC) control group. High control were programmed to gain 1 kg/d on a high-concentrate diet for the 40 w trial while LC was programmed to gain 0.5 kg/d on a high-forage diet. The stair-step groups were fed in 4, 10 w periods with SS-1 being fed *ad libitum* intake on high concentrate, followed by restriction on a high-forage diet (programmed to gain 0.35 kg/d), *ad libitum*, restricted; with SS-2 being fed the reverse of SS-1 beginning with restricted intake. They observed SS-2 gained at a faster rate in the later half of development compared to SS-1 which is expected due to the opposite order in the timing of restriction between the nutrition regimens. No difference in age at puberty was observed between SS-1 and HC, with SS-2 still having a hastened onset of puberty compared to LC. These results suggest a stair-step program can be expected to achieve reproductive success similar to heifers fed at a steady high-plane of nutrition. Grings et al. (1999) also used multiple diets to regulate gain in a stair-step regimen and found no difference in the age of puberty compared to the control group.

Requiring multiple diets to be formulated and alternated in a multi, stair-step program is potentially burdensome from a storage and delivery prospective. A moderate to high-energy diet fed at varying levels of intake may be more feasible for a producer. It would also be beneficial to have a method of programming gain at the beginning of the development period with confidence of reaching an end target BW without constant monitoring and adjustment of intake. Heifers in the previously mentioned studies were also fed in a dry-lot setting for extensive periods of time ranging from approximately 24 (Grings et al., 1999) to 40 (Cardoso et al., 2014) weeks. What if heifers were managed on a lower plane of nutrition, such as on pasture alone, post-weaning prior to being exposed to a shorter stair-step development regimen closer to breeding? In this program, heifers would be experiencing more of a late gain development strategy, as demonstrated by Lynch et al. (1997). Delaying weight gain until the last third of the developmental period as opposed to a steady, even-gain strategy did not effect end BW or pregnancy rate but did reduce overall feed costs by 2.5% (not statistically significant; Lynch et al., 1997).

Effect of exogenous factors on the onset of puberty

Developing on continuous low planes of nutrition have been shown to impact the ability of heifers to reach puberty prior to breeding compared to those developed on high-planes of nutrition or stair-step regimens (Cardoso et al., 2014). To further mitigate risk associated with developing heifers, it is important to recognize the impacts exogenous sources can have on inducing puberty and aiding in reproductive success. Estrus synchronization is a useful tool in obtaining a more uniform calf crop and aiding in the AI process. Additionally, synchronization has also been shown to induce puberty in prepubertal heifers (Gonzalez-Padilla et al., 1975; Short et al., 1976; Patterson et al., 1990). Wood Follis et al. (2004) observed feeding melengestrol acetate (MGA), a progesterone-like compound, for 14 d followed by a timed injection of GnRH and $PGF_{2\alpha}$, or $PGF_{2\alpha}$ alone, both showed the ability to induce puberty in prepubertal heifers. Synchronized pregnancy rates for prepubertal heifers were 64% as opposed to 74% for pubertal, with final pregnancy rates being 97 and 93%, respectively. While this approach was successful, MGA can be difficult to feed without adequate facilities and ensuring all animals are receiving the correct dosage is difficult to monitor, thus other progestin based protocols may be more feasible.

Leitman et al. (2014) compared various protocols to evaluate their ability to synchronize estrus and induce ovulation in both cycling and prepubertal heifers. Using a CIDR Select protocol, where heifers were exposed to a CIDR prior to GnRH and PG, induced puberty in 12 out of 14 prepubertal heifers as opposed to Select Synch + CIDR which only induced 4 out of 11 prepubertal heifers. Similar findings were observed for the previously cycling heifers as well. These results support the concept of presynchronizing with progestin before GnRH and PG is more effective at synchronizing estrus in mixed groups of cycling and prepubertal cattle. It is worth noting, Burfening (1979) suggested that because puberty is a heritable trait, relying on induction of puberty over multiple generations might result in attainment of puberty being increasingly difficult without hormone treatment. While this cannot be completely overlooked, utilizing synchronization protocols to induce puberty, especially in late maturing animals of adequate BW, can improve reproductive success of replacement heifers.

Feeding ionophores (a family of antimicrobial feed additives utilized in ruminant diets to increase feed efficiency; Bergen and Bates, 1984), such as monensin, has decreased age at puberty (Moseley et al., 1977; Moseley et al., 1982). Moseley et al. (1982) observed an overall decrease in age at puberty in heifers fed monensin as opposed to a control diet. This response did not appear to be caused by an increase in ADG or BW. The mechanism by which monensin affects age at puberty has not been determined but is thought to be caused by influences on the maturation of the endocrine system. Prepubertal heifers fed monensin have greater responsiveness to exogenous gonadotropin stimulation (Busmich et al., 1980) as well as estradiol and GnRH (Randel et al., 1980; Randel and Rhodes, 1980) which could explain the increased incidence of puberty. A connection is also thought to exist between onset of puberty and rumen fermentation/energy metabolism, specifically the increased production of propionate observed with exposure to dietary monensin (McCartor et al., 1979). With these observations in mind, feeding monensin to prepubertal heifers combined with a synchronization protocol that involves exogenous GnRH may improve overall reproductive success.

Selection of a heifer development program

Replacement heifers are necessary to sustain an operation (Clark et al., 2005), with cow longevity and herd productivity being influenced by the overall herd age; as a cow ages her productivity eventually diminishes (Rogers, 1972). That being said, a beef herd manager must determine whether it is most appropriate for their operation to buy or raise replacements. Assuming they decide to raise their own replacements, a variety of factors must be considered to optimize the development process including all biological, economic, and personal constraints (Stygar et al., 2014). A development strategy must also consider the goals and requirements of the operation such as necessary replacement rate and feed availability. Necessary replacement rate in a herd varies if the operator is increasing (more replacements) or maintaining herd size and is dependent on cull rate, death loss, and calf prices (Rogers, 1972). Raising replacement females can strain a producer as it decreases cash flow, not selling calves at weaning, and increases expenses in feed and management costs.

Incorporation of multiple factors effecting cost of development is important in the evaluation of a development program. The consideration of net present value (NPV) of a retained heifer-calf is important because current cash flow is reduced by not selling a heifer at weaning. Net present value refers to the net cash flows resulting in the future from an investment, less the cost of the initial investment (Kay et al., 2016). Brood cow value peaks at about 3 years of age when they have proven themselves productive and the present value is greatest in the 3-4 year range as their sale value exceeds cost of production (Rogers, 1972). In the mean time, a producer will also ideally receive income from the one or two calves weaned from that female.

To keep cost of development down and further increase NPV, optimal management strategies should be considered. As previously mentioned, the ideal target BW at breeding has been under revision from 60-65% MW to a lesser range; anywhere from 50-58% MW. Recent research by Funston and Deutscher (2004), Martin et al. (2008), and Lardner et al. (2014), among others, have demonstrated heifers can be developed to a lesser percent of MW, with no decrease in reproductive success, for less as opposed to conventional methods. Funston and Deutscher (2004) reported a $22/heifer decrease in feed costs for heifers developed to 53% MW as opposed to 58%. Reduced feed costs play a key role in economic feasibility.

When selecting a heifer development program for an operation many factors must be considered including the breed, goals of the operation, and current working capital. It is an upfront investment to retain heifers as opposed to selling at weaning; however, replacements are required for sustainability of a cow-herd and the NPV of heifers should be considered. Comparing various strategies that incorporate diverse approaches to modifying plane of nutrition, rate, and timing of gain to decrease overall input costs may lead to more consistent and profitable decision making. Unfortunately, operators often utilize a heuristic approach when selecting a development program. Heuristics are strategies of decision making which can be described as cognitive processes that ignore part of the information, consciously or unconsciously, with the goal of making decisions more quickly than complex methods (Gigerenzer and Gaissmaier, 2011). The effort saved using heuristics implies greater error than “rational” decisions as defined by logic or statistical models which can lead to increased development cost to the producer. A management decision tool that is able to compare a variety of development programs for optimal performance based on individual operation-based decisions could prove useful at mitigating error while still requiring little effort by the operator.

CHAPTER II

PRODUCTION AND ECONOMIC EFFECTS OF DEVELOPING HEIFERS ON THREE DIFFERENT LEVELS OF STAIR-STEP NUTRITION PROGRAMS

Synopsis

Links between nutrition and reproductive success in heifers are well established; however, achieving a high plane of nutrition is costly, and reproductive success remains uncertain, making heifer development both expensive and risky. Development could be optimized by creating nutritionally efficient strategies that manage plane of nutrition without negatively impacting reproductive success. At an average age of 340 d (209 kg), 85 heifers were randomly assigned to 1 of 3 treatments: high (H, $n = 29$), programmed to gain 0.92 kg/d, medium (M, $n = 28$), 0.45 kg/d and low (L, $n = 28$), 0 kg/d from d 0 to d 49 (P1). All heifers were then programmed to gain 1.36 kg/d from d 50 to d 90 (P2). Heifers were individually fed a common diet (42% cracked corn, 26% DDG, 26% alfalfa hay, and 6% molasses; 14.0% CP, 1.1 Mcal NEg/kg) at different levels to achieve programmed rates of gain. Weekly BW and blood samples were collected. Digestion was measured beginning on d 41 (P1) and on d 83 (P2). All heifers were synchronized beginning on d 90 using the Bee-Synch protocol for fixed-time AI on d 98, followed by 56 d exposure to bulls. Pregnancy rates were determined on d 154. Gain differed between treatments in P1 ($P < 0.01$); M- and L-fed heifers exceeded programmed gain by 0.16 and 0.37 kg/d respectively (H = 0.83, M = 0.61, L = 0.37 kg/d), and tended to differ ($P = 0.07$) in P2 (H = 1.31, M = 1.41, L = 1.37 kg/d). Digestion in P1 differed ($P = 0.01$) between heifers fed H (86.2% DM) and L (88.7% DM); no differences ($P = 0.23$) were observed in P2. Total ADG and input costs were different among treatments ($P < 0.01$). Cost of development for the M and

L treatments were $10 and $23 less per heifer, respectively, than H ($95.35). Body weight and number pubertal on d 90 were not different ($P \geq 0.10$). Pregnancy rates on d 260 were not different ($P = 0.99$) being 97, 100, and 96% for H, M, and L, respectively. Developing heifers on a lower plane of nutrition decreased cost per pregnancy without apparent negative effects on reproductive success. The L strategy was the optimal development program based on cost per pregnancy; however, additional research is needed to confirm the effects on reproductive outcomes.

Introduction

Traditional methods of raising replacement heifers come at a great cost and risk to producers as they must maintain high planes of nutrition with uncertainty of reproductive success. The main goals of heifer development are well defined; a heifer is expected to reach puberty and conceive early, sustain pregnancy, calve unassisted as 2-year-olds, and rebreed within 120 d postpartum, all for a minimal cost (Lardner et al., 2014). The general recommendation is for heifers to be developed to 60 to 65% of mature BW prior to breeding to optimize reproductive success (Patterson et al., 1992). However, straight *Bos taurus* heifers reaching less than 60% mature BW by breeding did not have reduced reproductive performance (Funston and Deutscher, 2004; Martin et al., 2008; Lardner et al., 2014).

A stair-step development program manages diet utilization, decreasing overall feed costs by lowering apparent maintenance requirements and increasing overall nutrient availability to the animal, without compromising attainment of puberty (Grings et al., 1999; Cardoso et al., 2014). Dietary manipulations used by Grings et al. (1999) and Cardoso et al. (2014) were completed by alternating multiple diets in a dry-lot for set periods of time; a strategy that may not be feasible for some producers. Heifers managed on a lower plane of nutrition, such as on pasture alone, post-weaning prior to being exposed to a shorter stair-step development regimen closer to breeding could be expected to perform similarly but requiring less management and reduced input costs. Lynch et al. (1997) reported no decrease in pregnancy rate on *Bos taurus* heifers experiencing delayed weight gain until the last third of development as opposed to a steady, even gain strategy; whether similar effects would be observed in *Bos indicus*-influenced heifers in unknown.

The majority of heifer development strategies that have been researched target *Bos taurus* hiefers (Funston and Deutscher, 2004; Gasser et al., 2006; Martin et al., 2008; Larner et al., 2014). Considering the marked physiological differences between *Bos taurus* and *Bos indicus* breeds (Sacco et al., 1987; Nogueira, 2004), there is an apparent need for studying different approaches to develop *Bos indicus*-influenced heifers. Objectives of the current study were to determine if developing *Bos indicus*-influenced heifers on a lower plain of nutrition; managing diet utilization, would decrease costs of development without sacrificing reproductive performance.

Materials and methods

This research was conducted according to experimental protocols approved by the Institutional Animal Care and Use Committee at Texas A&M AgriLife Research.

Eighty-five crossbred (1/8 to 1/4 *Bos indicus*) beef heifers were weaned at 222 ± 43 d of age (d -93), weighed, and held under common management for 93 ± 4 d at the McGregor Research Center, McGregor, TX. Prior to beginning treatments, heifers were stratified by herd origin and initial BW. Within strata heifers were randomly assigned to one of 30 pens equipped with individual Calan gate feeders (American Calan, Northwood NH). Within pens heifers were randomly assigned to 1 of 3 treatment groups: high (**H**, *n* = 29), medium (**M**, *n* = 28), or low (**L**, *n* = 28). All heifers consumed a common diet consisting of cracked corn (42%), DDG (26%), alfalfa hay (26%), and molasses (6%) and 76 g of a rumensin pre-mix top-dressed daily (approximately 100 mg monensin/d; Table B1). The diet was formulated and fed to achieve targeted ADG for each treatment consisting of 0.92 kg/d (H), 0.45 kg/d (M), or 0 kg/d (L) from d 0 to d 49 (**P1**). All heifers were then programmed to gain 1.36 kg/d from d 50 to d 90 (**P2**) the reason being, based on projected BW at d 45, it would require 1.36 kg/d for H to meet a traditional target BW (60% mature BW; mature BW estimated as 522 kg). Daily feed amounts for each animal were determined by first determining the average, maximum, and minimum starting BW for each treatment group and calculating the projected mid-weight of each, based on programmed gains. Using predicted BW at d 49 as the end BW goal for P1, the % BW of feed required to reach that goal was determined for average, maximum, and minimum starting BW using the NRC prediction equations (NRC, 2000). These three values were averaged together to get one % BW value for each treatment group. Individual animals' starting BW were then multiplied by their respective treatment's value to determine daily intakes. A similar procedure was utilized to determine intake amounts in P2 estimating the end weight as the predicted BW at d 90 as predicted by the desired programmed gain from d 49.

Heifers were initially adapted to housing and feeding protocols for 17 d on a common diet (42% cracked corn, 26% DDG, 26% alfalfa hay, and 6% molasses) at 3.6 kg/d with continuous access to water; heifers were housed in pens with a maximum of 3 animals/pen in an open sided barn. At 329 ± 43 d of age heifers (203 ± 43 kg) began their pre-programmed treatments with daily feeding at 0800h. On d 49 heifers were gradually adapted to their increased P2 daily intake over a 7 d period. Weekly blood samples and BW were obtained throughout the entirety of the project for determination of puberty status and estimated ADG. Blood was collected from the jugular vein by venipuncture into serum separator vacutainer tubes and placed on ice until collections were complete. Samples were centrifuged and pipetted into 1.5 ml micro centrifuge tubes and frozen at -20˚C until analyzed.

Measurements of intake and digestion were made from observations made d 41 through d 43 (P1) and d 83 through d 85 (P2) for 10 randomly selected animals from each treatment group; animals were randomly selected for each period. Fecal production was estimated using acid detergent insoluble ash (ADIA) as an internal marker. Grab samples were collected every 12 h with sample time advancing 4 h each day so that 6 samples were obtained over each 3 d collection period. Fecal samples were individually frozen and stored at -20^{o}C. Prior to analysis, each sample was thawed and thoroughly mixed before being composited, by weight, for each period/heifer.

On d 90 all heifers were synchronized using the PG 5-day CO-Synch + CIDR protocol, “Bee Synch,” for fixed-time AI for *Bos indicus*-influenced cattle (Figure B1). Heifers received a 5ml injection of Lutalyse ($PGF_{2\alpha}$; Pfizer Animal Health, New York, NY) and 2 ml Factrel (GnRH; Zoetis Inc., Madison, NJ) on d 0 and a controlled internal drug release (CIDR) insert (Pfizer Animal Health, New York, NY). Controlled internal drug release removal occurred on d 5 and 4 ml of Lutalyse was administered in two 2 ml doses, 6 hours apart. On d 8 of synchronization 10 ml of Factrel was administered at the time of AI. Heifers were turned out with bulls on common pasture for 56 d. Pregnancy status was determine on d 126 and d 154 via blood samples collected from the jugular vein by venipuncture into serum separator vacutainer tubes and placed on ice until analyzed. Final pregnancy status was determined on d 260 via palpation.

Laboratory analysis

Diet and fecal samples were dried in a forced-air oven for 96 h at 55°C and allowed to air-equilibrate then weighed for determination of partial DM. Diet samples were composited within period. Fecal samples were composited within heifer for each period. Diet and fecal samples were then ground through a 1-mm screen using a Wiley mill (Thomas Scientific, Swedesboro, NJ) and dried at 105°C for 24 h for determination of DM. Organic matter was determined as the loss in dry weight upon combustion in a muffle furnace for 8 h at 450°C. Analysis for ADF was performed using an Ankom Fiber Analyzer with sodium sulfite omitted and without correction for residual ash (Ankom Technology Corp., Macedon, NY) and determination of ADIA was ran by combusting the ADF residue in a muffle furnace for a minimum of 8 h at 450° C. Energy values were determined by direct calorimetry using a Parr 6300 Calorimeter (Parr Instrument Co., Moline, IL). Individual diet ingredients were sent to a commercial laboratory (SDK Labs, Hutchinson, KS) for analysis of crude protein and TDN.

Circulating progesterone levels were determined in duplicates using a commercial RIA kit (MP Biomedical, Santa Ana, CA). Samples were thawed in a refrigerator for 12 h and 100 µl of serum was pipetted into coated tubes. 1.0 ml of Progesterone-^{125}I tracer was added and tubes were briefly centrifuged and incubated for 2 hours in an oven at 37°C before being decanted and counted on a gamma counter. Mean sensitivity of the assay was 0.02 ng/mL with mean intra- and inter-assay CV of 5.3% and 8.3%, respectively. Blood analysis for pregnancy determination was performed by Texas A&M Veterinary Medical and Diagnostic Lab (College Station, TX) via BioPRYN bovine pregnancy test (BioTracking, Inc., Moscow, ID).

Calculations

Fecal production was calculated using:

$$\text{Fecal production, kg DM/d} = \frac{\text{Diet ADIA (g/d)}}{\text{Fecal ADIA concentration (g/kg DM)}}$$

where:

Diet ADIA = ADIA in Diet (g/kg DM) × DMI (kg/d)

Fecal ADIA concentration = Fecal ADIA concentration (g/kg) ÷ Fecal DM (%)

Digestibility of DM, OM, ADF were calculated using:

$$\text{Digestibility, \%} = \left(\frac{\text{Intake} - \text{Fecal}}{\text{Intake}}\right) \times 100$$

where:

Intake = DMI (kg/d) × dietary nutrient concentration (% DM)

Fecal = Fecal production (kg DM/d) × fecal nutrient concentration (% DM)

Digestible energy intake (DEI) was calculated using:

DEI, Mcal = GEI – FE

where:

GEI = DMI (kg) × Dietary energy concentration (Mcal/kg DM)

FE = Fecal production (kg DM/d) × Fecal energy concentration (Mcal/kg DM)

Cost of development (COD) was calculated using:

COD ($/hd) = TMR cost ($/kg) × DMI (kg/d)

Cost per pregnancy (CPP) was calculated for each treatment using:

$$\text{CPP (\$/pregnancy)} = \left(\frac{\text{Cost of development (\$/hd)} \times \text{Total number of hd}}{\text{Number bred}}\right)$$

Statistical analysis

Intake, digestion, BW, ADG, cost of development, and cost per pregnancy were analyzed using the PROC MIXED procedure in SAS 9.3 (SAS Inst. Inc., Cary, NC). Model fixed effects included treatment. Percent pubertal and percent bred were analyzed using the GLIMMIX procedure in SAS 9.3 (SAS Inst. Inc., Cary, NC). Model fixed effects included treatment.

Results

Dry matter, GE, and DE intake were different ($P < 0.01$) between all treatments in P1 (Table B2). Dry matter, OM, and ADF digestion were different ($P < 0.04$) between H and L in P1. A difference ($P = 0.01$) in DM, GE, and DE intake was observed for L in P2, however, DM, OM, and ADF digestion did not differ ($P \geq 0.23$). The increase in DM intake between P1 and P2 was different among all treatments (P < 0.01).

No differences ($P \geq 0.59$) in ADG (Table B3) or BW (Table B4) from weaning (d -93) to the start of programmed development (d 0) were observed. Average daily gain was different ($P < 0.01$) between all treatments in P1, and tended ($P = 0.07$) to be different in P2 as well. A difference ($P < 0.01$) in total ADG was observed with L being lower than H and M. Body weight on d 49 was least ($P = 0.01$) for L, with no difference observed for H and M. BW on d 90, 126, and 154 were not different ($P \geq 0.10$). Cost of development, determined using feed costs with all other costs considered constant between treatments, was different ($P < 0.01$) among all treatments.

There was no difference between treatments of the percent pubertal (Table B5) throughout development ($P \geq 0.32$) and no statistical difference ($P \geq 0.21$) was detected in pregnancy rate on d 126, 154, or 260 (Table B6). Cost per pregnancy on d 260 was different ($P < 0.01$) between treatments with L being the least cost option at \$75.10/hd, followed by M \$84.89/hd, and H \$98.76/hd.

Discussion

Based on predicted NE_g (NRC, 2000) values, intake of each diet was set for P1 such that heifers would gain 0.92, 0.45, or 0 kg/d for H, M, L, respectively. Accordingly, DM intake, was different for each treatment being least for L (2.61 kg DM/d) and greatest for H (4.38 kg DM/d). This resulted in different levels of GE and DE intake between all treatments. Dry matter intake differed for L in P2 consuming 5.89 kg/d as opposed to 6.34 and 6.59 kg/d for M and H, respectively. Subsequently, both GE and DE intake were also lower for L. All heifers were programmed at the beginning of the project to gain the same amount in P2, 1.36 kg/d, based on their projected d 49 BW. Low had been projected to gain 0 kg/d in P1 meaning their starting BW and d 49 BW would be equal; however, L heifers gained 0.37 kg/d, on average. Assuming they would weigh the same at d 49 resulted in a lower predicted NE_g requirement and, in turn, a lower predicted intake requirement to achieve the desired gain in P2.

High and L had different digestion coefficients for DM, OM, and ADF with low having the greatest digestion, 88.7% DM. Mertens (1983) modeled an explanation for decreased digestion with increased passage rate occurring as a result of increased feed intake which was also supported by Colucci et al. (1984) and Adams and Kartchner (1984). Assuming the reverse is true, with L and M being fed less DM than H, it is expected that extent of digestion of the diet would be greater as a result of slower passage rate. Conversely, in P2; there was no difference in digestion coefficients for DM, OM, and ADF despite L and M having a lower DM intake than H. Dry matter digestion was 80.7, 79.3, and 76.4% for H, M, and L, respectively. An explanation for an apparent decrease in digestion from P1 to P2 can be accounted for by the increased levels of intake (Mertens, 1983). The change in DM intake from P1 to P2 was greatest for L (3.41 kg/d) followed by M (3.07 kd/d) compared to H (2.67 kg/d).

There was no difference in ADG from weaning to the beginning of programmed gain, thus the weaning period of 93 d on pasture can be considered the initial “step” of the program with ADG being, on average, -0.24 kg/d for all treatment groups. By design, there was no difference in starting BW among treatments. After d 49 on treatment, L weighed significantly less (227 kg) than M (241 kg) or H (247 kg). Observed ADG was different between treatments H, M, and L gained 0.83, 0.61, and 0.37 kg/d, respectively with M and L both out performing the predicted rate of gains for P1 by 0.16 and 0.37 kg/d, respectively. Heifers fed at or near maintenance have previously been shown to outperform NRC predicted gains (Clanton et al., 1983; Lynch et al., 1997). Heifers that were predicted to gain 0.11 kg/d actually gained 0.14 and 0.25 kg/d over a 94 (Clanton et al., 1983) or 112 d (Lynch et al., 1997) period, respectively. It was suggested the increase in NE_g efficiency is not accounted for in the net energy system for heifers fed near maintenance and the NRC (NRC, 2000) underestimates gain in limit-fed heifers. There was a realimentation period for the second half of both these studies during which heifers outperformed predicted gain, with an additional gain of 0.23 kg/d over predicted amounts. Average daily gain between treatments tended to be different during P2 of the current study; however, only slight outperformance occurred by M (+ 0.05 kg/d) and L (+ 0.01 kg/d). The outperformance observed in P1 of this study resulted in an excess of 0.16 and 0.37 kg/d for M and L, respectively, which are of larger margin than those observed by Clanton et al. (+ 0.03 kg/d; 1983) or Lynch et al. (+ 0.14 kg/d; 1997). This outperformance could be related to heifers not meeting maintenance requirements in the post-weaning period, as demonstrated by the -0.24 kg/d ADG. Greater performance in P1 may explain the minimal outperformance in P2, as heifers’ intakes were set based on projected d 45 weights. Outperformance in P1 led to greater BW on d 45 than what was used to set intakes for P2. Thus, heifers were not actually fed sufficient NE_g to gain 1.36 kg/d based on the NRC, especially L. It is reasonable to assume in P1 maintenance levels could have been decreased for M and L, due to restricted intake, resulting in an apparent increase in efficiency (Freetly and Nienabar, 1998). Previous research has also demonstrated a decrease in visceral organ mass (VOM) especially of the liver and gastrointestinal tract, are influenced by plane of nutrition and highly related to fasting heat production and a decrease in overall metabolic activity (Ferrell and Jenkins, 1985; Koong et al., 1985; Burrin et al., 1990; Yambayamba et al., 1996). With energy expenditure by visceral organs comprising a major proportion of basal energy expenditure (Ferrell and Jenkins, 1985), it is reasonable that this played a role in the observed efficiency increase in the early stages of P1. However, we hypothesize the apparent increase in efficiency in P1 is mainly due to the restricted levels of intake allowing for slower passage rate and in turn increased extent of digestion/diet utilization (Mertens, 1983; Colucci et al., 1984; Kartchner 1984). By d 90, there was no statistical difference in BW among treatments being 307, 309, and 294 kg for H, M, and L respectively. Compared to projected end BW at the start of the study, H reached the targeted BW (307 kg) while M and L both surpassed their projected values (288 and 265 kg, respectively) by 7.3 and 10.9 %, respectively. Body weight measurements at d 126 and 154 were also not different between treatments. By d 154 heifers were 341, 345, and 334 kg for H, M, and L, respectively, equating to approximately 65, 66, and 61% mature BW. In contrast to other stair-step research (Grings et al., 1999; Cardoso et al., 2014), the current study suggests gain does not need to begin until the last half of the development period, in accordance with findings of Lynch et al. (1997). Despite a gain of -0.24 kg/d for the first 93 d, heifers were able to reach acceptable levels of BW during later programmed gain and continued to perform well when turned out to common pasture after programmed gain ended.

Percent pubertal was determined in approximately one month increments on d 0, 28, 56, and 90. There was no significant difference ($P \geq 0.32$) at any mentioned time point, however, on d 90 percent pubertal were 52, 46, and 32%, respectively, for H, M, and L. Previous researched has considered a heifer was pubertal if serum progesterone concentrations were $\geq$ 1 ng/mL for at least 2 consecutive samples when blood was collected twice weekly (Cardoso et al., 2014). In the current study collections took place once weekly, making it more difficult to determine cyclicity. For this reason, collection of one sample with $\geq$ 2 ng/mL progesterone or two consecutive samples of $\geq$ 1 ng/mL progesterone were considered to be indicative of puberty. On d 90 there were 16 heifers with serum progesterone levels greater than 1 ng/ml, suggesting these heifers were approaching onset of puberty around d 90. These heifers, however; were reported as non-pubertal at time of synchronization as they failed to meet the predetermined standards. Previous research conducted over three consecutive years by Clanton et al. (1983) developed heifers on a program outlined comparable to M. Heifers were programmed to gain 0 kg/d in period one followed by 0.91 kg/d in period two. Percent exhibiting estrus by breeding was 85% for this group. Heifers in their study were fed for 185, 170, or 173 d depending on the year. In the current study, heifers were fed approximately half the amount of time, 90 d, and therefore M may provide an accurate comparison. Heifers in the Clanton et al. (1983) study were programmed for 0.91 kg/d for approximately 90 d which is the same as the average rate of programmed gained for M over the 90 d feeding program, however; only 46% of heifers were considered pubertal by the time of breeding in the current study. Heifers in the current study had a greater BW at breeding therefore it is not likely due to inadequate BW, but rather breed type could play a role in timing of puberty. Clanton et al. (1983) utilized Angus × Herford heifers while the current study utilized *Bos indicus*- influenced crossbred heifers. Heifers of *Bos indicus* breed type have been shown to have a later onset of puberty (Sacco et al., 1987; Nogueira, 2004) which may explain the observed differences.

Pregnancy rate on d 126 was determined via a BioPRYN (BioTracking, Inc., Moscow, ID) assay. Observed pregnancy rates were 44.8, 57.1, and 40.7% for H, M, and L, respectively, there was no statistical difference. Blood collected on d 126, 28 d post-AI, would only show pregnancy for those that conceived on the initial AI-heat. Because heifers were exposed to bulls immediately after AI, it is possible heifers that did not conceive via AI could have been bred natural service; however, d 126 rates accurately represent all heifers bred on the initial heat of the breeding season. Pregnancy rates on d 154, also determined via a BioPRYN assay, were 79.3, 96.4, and 82.1% for H, M, and L, respectively. Again, no statistical difference was detected. Day 154 pregnancy rates represent heifers bred by their second heat of the breeding season (first heat post-AI); consequently, heifers that will calve earlier within the calving season, which have been shown to exhibit higher lifetime production potential overall (Lesmeister et al., 1973). In terms of lifetime potential, M may be considered the most efficient program; however, further research should be conducted to determine treatment affects on lifetime productivity. Final pregnancy rates determined via palpation on d 260 were not different between treatments being 96.6, 100, and 96.4% for H, M, and L, respectively. It is generally recommended for heifers to have reached puberty 2-3 months prior to breeding for optimal pregnancy rates. Previous research reported heifers bred on third estrus had a 21% increase in pregnancy rate as opposed to heifers bred on pubertal estrus (Byerley et al., 1987). Being that only 32-52% of heifers were pubertal prior to the breeding date, it is possible reproductive success could have been improved via estrus synchronization. Synchronization has been shown to induce puberty in prepubertal heifers (Gonzalez-Padilla et al., 1975; Short et al., 1976; Patterson et al., 1990). Heifers subjected to an

MGA-based synchronization protocol had increased pregnancy rates for prepubertal heifers (64%) as well as previously pubertal heifers (74%), with final pregnancy rates being 97 and 93%, respectively (Wood Follis et al., 2004). In terms of % mature BW, H, M, and L reached 59, 59, and 56% respectively. Previous research has reported no decrease in pregnancy rate for heifers developed to 50 - 55% as opposed to 60% mature BW (Funston and Deutscher, 2004; Martin et al., 2008; Lardner et al., 2014) which is supported by the current study. Later reproductive performance, such as incidence of dystocia, is not likely to be impacted either. Funston and Deutscher (2004) reported no difference in calving difficulty scores for heifers developed to 55 or 60% mature BW. In addition, with heifers in the current study continuing to gain at adequate rates post development, no calving difficulty should be expected as a result of limit feeding or breeding at a BW lower than a traditional target weight.

Results of this experiment indicate that heifers can be developed on a lower plane of nutrition, managing diet utilization in the later half of development, decreasing overall cost of production, without sacrificing reproductive performance. Regardless of the program used, there was no difference in age at puberty, end BW, or pregnancy rate; however, L resulted in the least cost per pregnancy. Further research should be conducted to accurately determine the treatment effects on pregnancy and lifetime performance of heifers and their calves.

CHAPTER III

AN ECONOMIC COMPARISON OF CONSTANT-GAIN AND STAIR-STEP HEIFER DEVELOPMENT PROGRAMS TO AID IN MANAGERIAL DECISION MAKING

Synopsis

Replacement heifers are vital to the sustainability of an operation, and there are a multitude of strategies by which heifers can be developed. Traditional development programs are based on a constant-gain approach with the goal of meeting an end target BW at breeding while stair-step approaches take advantage of managing diet utilization and can decrease overall feed costs by reducing inputs. With various strategies being viable options in terms of successfully achieving pregnancy, it is often difficult to determine which is the best decision, economically, for a specific operation. A heuristic approach can easily be applied, subconsciously, to making managerial decisions, potentially leading to increased error in decision making. Therefore, a decision tool was created comparing five development programs: 1) constant-gain from weaning to breeding with a target BW of 62% mature BW (MW), representing a traditional development program; 2) constant-gain from weaning to breeding with a target BW of 55% MW, representing a riskier but lower input approach to traditional methods; 3) high-plane stair-step 4) medium-plane stair-step; and 5) low-plane stair-step; where planes represent varying levels of nutrition. Programs were compared using net cost per pregnancy (CPP) to determine the optimal strategy, based on rational decisions, that would likely prove more consistent over time. A sensitivity analysis was conducted to evaluate the extent to which each variable impacted CPP. Cost at weaning was the most influential factor when selecting an optimal program, followed by other

losses (related to death and mechanical loss), and yearling heifer price. Overall the tool proved successful at aiding in making a rational decision.

Introduction

Replacement heifers are necessary to sustain an operation (Clark et al., 2005); however, whether they are purchased or raised is a decision that must be based on the operation's biological, economical and managerial constraints (Styar et al., 2014). If developing replacement heifers, additional decisions must be made regarding a development program. Traditional, conservative, development programs are based on the goal of meeting a pre-determined target BW at breeding that is thought to be associated with a maximized pregnancy rate (Patterson et al., 1992). Conservative BW targets range from 60 to 65% mature BW (MW; Patterson et al., 1991; Patterson et al., 1992); however, recent research has suggested similar pregnancy results can be obtained at target BW of 50 to 60% MW (Funston and Deutscher, 2004; Martin et al., 2008; Lardner et al., 2014). Strategies with lesser target weights can decrease input requirements without negatively impacting reproduction (Funston and Deutscher, 2004). Classic development strategies imply achieving a constant rate of gain post-weaning (approximately 7 to 8 months of age) through breeding (approximately 13 months of age); however, achieving and maintaining a high plane of nutrition over the 6-month development period may be costly even if target BW is reduced.

One strategy for mitigating costs of heifer development is to utilize a "stair-step" or "phase-feeding" development program, manipulating planes of nutrition to manage diet utilization; decreasing overall feed requirements by lowering maintenance requirements (as a proportion of total feed utilized) without compromising attainment of puberty (Grings et al., 1999; Cardoso et al., 2014). For example, providing minimal supplemental nutrition to grazing heifers until the last one third of development, eliminating any additional feed costs during the first 3 months post-weaning, and implementing a two-phase supplemental feeding program to further utilize any retained efficiency advantages (Chapter II).

While various strategies have been successful at achieving acceptable pregnancy rates in virgin heifers, it is often difficult to determine which is the best decision, economically, for a specific operation. Heuristics are strategies of decision making extensively studied in psychology which can be described as cognitive processes that ignore part of the information, consciously or unconsciously, with the goal of making decisions more quickly than complex methods (Gigerenzer and Gaissmaier, 2011). A heuristic approach can easily be taken in choosing a development program; for example, when deciding between a constant-gain or stair-step strategy, one may rationalize the constant-gain being a better option based on prior knowledge that the shortest distance between two points (two BW values) is a straight line; however, various factors are being ignored such as potential differences in total feed required and/or relative risk between the two strategies. There also tends to be a bias toward over feeding heifers as well-conditioned heifers are more visually appealing, giving the illusion of being easier to breed; however, this heuristic based decision ignores the idea that over-conditioning can be just as detrimental as poor nutrition (Bowman and Sowell, 1998). The effort saved using heuristics may result in greater error than “rational” decisions as defined by logical or statistical models; however, the impact of this error on the decision being made can also be variable based on the size of error (Gigerenzer and Gaissmaier, 2011). A decision tool comparing development strategies based on a unique operating situation would provide managers the opportunity to compare different strategies, and the costs associated with them, to best make rational decisions that will likely prove more consistent over time.

Methodology

Five examples of development strategies were chosen for comparison in the decision tool: 1) constant-gain from weaning to breeding with a target BW of 62% mature BW (MW), representing a traditional development program; 2) constant-gain from weaning to breeding with a target BW of 55% MW, representing a riskier but lower input approach to traditional methods; 3) high-plane stair-step 4) medium-plane stair-step; and 5) low-plane stair-step; where planes represent varying levels of nutrition. Stair-step strategies were based on a previous experiment in which heifers were managed on dormant pasture for 90 d post-weaning followed by programmed gain of 2.0, 1.0, or 0.0 lb/d (high, medium, or low-plane of nutrition, respectively) for 45 d and 3 lb/d for the last 45 d prior to breeding for all programs (Chapter II). Even gain strategies were adapted from previous research (Lardner et al., 2014) in which heifers were fed a single diet from weaning to breeding.

All heifers consumed a common diet consisting of cracked corn (42%), DDG (26%), alfalfa hay (26%), and molasses (6%) and 76 g/hd of a rumensin pre-mix top-dressed daily (approximately 100 mg monensin/hd/d; Table C1). Intake amounts were determined based on NRC (2000) requirements to achieve a programmed rate of BW gain; constant-gain strategies were determined based on projected mid-weights from weaning to 55 or 62% MW, 180 d post weaning, to account for changes in maintenance requirements with increased body size/weight. Intake amounts for each stair-step program were obtained from a previous experiment (Chapter II) in which daily feed amounts for each animal were determined by first determining the average, maximum, and minimum starting BW for each treatment group and calculating the projected mid-weight of each, based on programmed gains. Using predicted BW at d 49 as the end BW goal for P1 (first 49 d of the 90 d feeding period), the % BW of feed required to reach that goal was determined for average, maximum, and minimum starting BW using the NRC prediction equations (NRC, 2000). These three values were averaged together to get one % BW value for each treatment group. Individual animals' starting BW were then multiplied by their respective treatment's value to determine daily intakes. A similar procedure was utilized to determine intake amounts in P2 (the last 41 d of the 90 d feeding period) estimating the end weight as the predicted BW at d 90 as predicted by the desired programmed gain from d 49. Total feed cost was calculated using:

Total feed cost = Feed cost ($/hd) + ionophore cost ($/hd)

where:

Feed cost = Diet cost ($/ton) × total feed (tons/hd)

Other assumptions (Table C3) included: weaning age (8 mo), weaning weight (WW; 515 lb), breeding season (60 d), and MW (1100 lb) all based on previous experiment values (Chapter II).

Each development strategy was assigned a high and low pregnancy rate (Table C4) representing the optimum (high) and conservative (low) expected pregnancy rate. For constant-gain strategies, pregnancy rates reported by Lardner et al. (2014) in which heifers were developed to 55 or 62% MW in two separate settings, were used. Pregnancy rates between the two settings for each of the MW targets were used as high and low rates accordingly. For stair-step strategies, pregnancy rates from the current experiment (Chapter II) were used as a starting base. Based on observed standard error of pregnancy rate means from previous research (Patterson et al., 1992; Lardner et al., 2014), pregnancy rates were adjusted by ± 4% for high and low plane stair-step and ± 2% for the medium plane strategy. Based on the expected pregnancy rates, and the desired number of replacements needed, the number of heifers required for each strategy was determined. The number of heifers required for retention at weaning was calculated using:

Heifers retained =

$$\left(\frac{\text{Females to replace (hd)}}{\text{Pregnancy rate (\%)}}\right) + (\text{females to replace (hd)} \times \text{other losses (\%)})$$

where:

Females to replace = Cows in herd (hd) × replacement rate (%)

Pregnancy rate = estimated pregnancy rate for individual development strategy

Replacement rate = % of females to be replaced in the herd; operation based

Other losses = expected % death and mechanical loss of heifers; operation based

The opportunity cost for retained heifers was calculated, representing the income that would have been realized if retained heifers were sold at weaning, using the equation:

Opportunity cost = Heifers required (hd) × weaned calf value ($)

where:

$$\text{Weaned calf value} = \left(\frac{\text{WW (lbs)}}{100}\right) \times \text{weaned calf price (\$/cwt)}$$

A partial budget approach was used for cost comparisons (Table C5); only costs associated with feeding were accounted for including (Table C2): yardage, pasture lease, ionophore, and ration cost. These costs were considered operation-based and can be modified as appropriate to a specific operation. Other operation-based inputs included; number of cows in herd; desired replacement rate; other losses (losses associated with death or mechanical losses); and prices for both weaned and yearling heifers. Total development costs were calculated for each program representing the feed costs associated with developing the respective number of retained heifers. Pasture costs were only applicable to stair-step strategies; a pen fee or yardage charge was applied for all strategies for the duration of time that heifers were not on pasture. Total development cost was calculated as:

Total development cost = (Total feed cost (\$/hd) + yardage cost (\$/hd) + pasture cost (\$/hd)) × heifers retained (hd)

where:

Pasture cost = pasture cost (\$/d) × days on pasture (d)

Yardage cost = yardage cost (\$/d) × days on feed (d)

Cull revenue was accounted for, representing the number of open heifers that could be sold as yearlings after the breeding season, calculated as:

Cull revenue = [heifers retained - (heifers retained (hd) × other losses (%)) – females to replace (hd)] × estimated yearling value (\$/hd)

where:

Estimated yearling value =

$$\left(\frac{\text{Estimated weight post-breeding (lbs)}}{100}\right) \times \text{yearling heifer price (\$/cwt)}$$

Estimated weight post-breeding =

Estimated development end weight (lb) + (90 (d) × 1.44 (lb/d))

Females to replace = Cows in herd (hd) × replacement rate (%)

Cost per pregnancy (CPP) was determined for each strategy as the most representative comparison of cost differences between programs. Cost per pregnancy was calculated using:

CPP =

$$\left(\frac{\text{Total development costs (\$) + Opportunity cost (\$) – cull revenue (\$)}}{\text{Heifers required for retainment (hd)} \times \text{pregnancy rate (\%)}}\right)$$

A sensitivity analysis was performed to determine factors with the greatest impact on overall CPP. For each scenario, each input variable was increased by 10%, *ceteris paribus*, and the resulting % change in CPP was determined.

Data

Pregnancy rates for each program were based on previous research. Constant-gain strategies were based on pregnancy rates reported by Lardner et al. (2014) where heifers were developed to 55 or 62% MW in one of two setting: pasture or drylot pens. Reported pregnancy rate in the drylot was 88% for those being developed to 55% MW while the pasture setting was 84%. For those developed to 62% MW pregnancy rates were 85 and 91% for drylot pens vs. pasture, respectively. Thus, 88% was used as the high pregnancy rate and 84% was used as the low for those developed via constant gain to a target weight of 55% MW while 91 and 85% were used as the high and low rates, respectively, for heifers developed to a target weight of 62% MW. Pregnancy rates from a current experiment (Chapter II) were used as a starting base for the stair-step programs. Pregnancy rates on d 154 were used which represent the first 30 d of the breeding season. Values of 79, 96, and 82 % (representing the high, medium and low plane, respectively) were adjusted by ± 4% for high and low plane stair-step and ± 2% for the medium plane strategy, adjustments were based on observed standard error of previous research (Patterson et al., 1992; Lardner et al., 2014). These rates (d 30) were chosen as opposed to final pregnancy rates (after 60 d breeding season) to represent heifers that would calve earlier in the calving season, as they tend to have higher potential lifetime productivity (Lesmeister et al., 1973) which would be arguably more advantageous in replacement heifer development. To estimate BW post breeding (90 d after the beginning of the breeding season, time of last pregnancy determination) a gain of 1.44 lb/d was used based on ADG values from a previous experiment (Chapter II). Post breeding BW represents the estimated weight at pregnancy determination when open heifers would be culled and sold at current market value. For demonstrative purposes, rational values were assigned for the operation-based decisions established on current market prices. Feed costs were calculated on a per ton basis based on average Fall 2017 ingredient prices.

Results and discussion

Figure C1 and C2 show the output "dashboard" and decisions page, respectively, of the resulting decision tool. Estimated CPP ranged from $923 to $979 across strategies evaluated. The least CPP of the 5 programs is highlighted in green. With current input data, the low-plane stair-step strategy resulted in the least CPP which was 5.7% less than the CPP for the constant-gain 62% strategy (which might be considered the most 'traditional' or conservative of those evaluated). The reduced CPP was primarily a function of decreased cost of development, less feed inputs, and increased revenue from culls. The spread of CPP between all strategies was less than anticipated; however, the tool attempts to capture a wide view of predicted outcomes and there are still aspects left unaccounted for that could possibly lead to greater separation.

The sensitivity analysis results (Figure C3) identify variables that impact the % change in CPP associated with each strategy. The direction of the impact of a given variable (positive or negative) was consistent; however, the extent to which a variable impacted CPP varied among strategies. Changes in weaned calf price had the greatest impact on change in CPP for all strategies, with low and high plane stair-step being the most impacted with a change slightly >10%, this is due to the greater number of replacements retained, increasing the value of opportunity cost without a subsequent increase in resale value post-breeding. For the low and high-plane stair-step strategies, weaned calf price can be considered a high leverage effect meaning the percent change in CPP was greater than the percent change in weaned calf price, however; the difference was less than 0.5%. Yearling heifer price was the only variable that caused CPP to decrease. Programs that had lower pregnancy rates realized the most impact, understandably, as they had the most open heifers to sell at the end of the breeding season. It is important to note that each variable was changed independent of the other for the sensitivity analysis while, in reality, multiple variables could change at once. For example, due to market changes, an increase in weaned calf price suggests mean yearling heifer prices would also increase and buffer this change.

A change in ‘other losses’ had the second greatest impact on CPP; again, programs that required a greater number of replacements due to a wide range in pregnancy rates (high and low plane stair-step) realized the greatest extent of impact. Programs with wider ranges in pregnancy rates are reflective of the higher risk associated with these particular strategies. Being that the low-plane stair-step program averaged a CPP nearly 6% less than the constant-gain with a target weight of 62% MW, the decreased cost of development may be worth the inherent risk. It is unlikely, while not impossible, that other losses, representing death and mechanical loss, would increase by 10% in an operation; however, if it occurred it is apparent that the more animals invested in a development program (the higher the associated risk), the greater the increase in CPP will be.

Ration cost, yardage, pasture lease cost, and replacement rate all had more moderate impacts on CPP while still showing variation between different strategies. Surprisingly, a 10% increase in ration cost only increased the CPP of constant gain strategies, at most, +0.6% compared to the change in CPP for the stair-step strategies, suggesting the greatest factors influencing CPP in the current decision tool output were related to weaned calf price and yearling heifer price. Because the heifers were profitable as stockers, given the current market prices, the development programs with the greatest number of cull heifers after the breeding season had the advantage of decreasing overall CPP.

The decision tool could be helpful in making a decision regarding which development program is best for an individual operation. The variable factors accounted for through the use of the tool, mitigates error that may be made in a heuristic decision approach. For example, one may overlook the impact weaned calf price has on overall CPP as it is easy to focus on more concrete variables such as feed inputs when trying to make a quick decision. For example, an increase of weaned calf price by 15%, with all other variables held constant, results in the strategy with the least expected CPP to be shifted from a low plane stair-step to medium plane (Figure C4). A drastic decrease in feed cost is required to shift the optimal strategy away from the low plane stair-step. Interestingly, when the ration cost is reduced by 56% (Figure C5) the optimal strategy shifts to high plane stair-step and both constant-gain and medium plane stair-step strategies are within $2 of each other at approximately $900/pregnancy. In contrast, high and low plane stair-step are approximately $880/pregnancy with the difference from other strategies being realized from the high returns from cull animal revenue.

While this decision tool is adequate for aiding in the selection of an optimal development program, future additions could further its accuracy and, in-turn, its consistency. Pregnancy rates for stair-step models were chosen to be rates that reflected earlier conception thus more likely resulting in early calving and greater overall lifetime productivity (Lesmeister et al., 1973). While the high and low pregnancy rates are presented as a way to represent the apparent risk associated with each strategy, the early breeding factor is not specifically accounted for in the current tool. To account for such variables, a component evaluating net present value would be beneficial. Net present value (NPV) refers to the discounted stream of future net cash flows resulting from an investment, less the cost of the initial investment (Kay et al., 2016). A heifer that is expected to perform more desirably in the future, being bred early in season, calving early, and raising a heavier calf at weaning, for more production cycles is more valuable than an animal who is likely going to be difficult to rebreed or fail to be bred within the desired breeding season over time. Being able to forecast an animal's future production potential gives greater insight to choosing an optimal development strategy as the greatest challenge is getting a heifer rebred with her second calf as opposed to the first (Clark et al., 2005). It was beyond the scope of the current project to attempt to estimate differences in future productivity that might result from different development strategies. If future production parameters are constant across strategies, then the only differences in NPV would be reflected in the initial investment amount (CPP). In addition, the current tool predicts values on a one-year basis, making it difficult to predict if results will continue to look the same overtime. For example, programs may indirectly result in the selection of more fertile heifers overtime, decreasing future replacement rates which could impact development program selection.

Diet is held constant in the current tool; an additional component that may be considered would allow for varying feedstuff utilization to decrease costs when reduced price ingredients are available. Changing the diet can impact the amount of feed required to meet programmed rates of gain, thus feed costs may not be directly related to ingredient price and selection. A diet component seems to be less impactful than one regarding NPV as the development diet affects only the initial investment amount, unless long term impacts on productivity exclusively as a function of development diet can be established. While CPP may increase or decrease, the various programs are likely to still rank similarly in terms of most optimal and thus the tool accomplishes its purposes of aiding in decision making without taking NPV into account.

The current decision tool reduces the error that could be made with a heuristic decision strategy using a more logical approach that encompasses a variety of factors that can affect the CPP associated with five development programs. The tool allows users to input information specific to an operation to best estimate an accurate, consistent outcome. It was observed that calf prices had the greatest impact on overall decision outcomes and thus should be considered an important factor to take into consideration when selecting a development program. Future improvement of the decision tool should include a component accounting for NPV of the developed heifers as the lasting implications of a development program decision were not completely accounted for.

CHAPTER IV

SUMMARY

Links between nutrition and reproductive success in heifers are well established; however, achieving a high plane of nutrition is costly, and reproductive success remains uncertain, making heifer development both expensive and risky. Previous research has indicated heifers can be developed to lighter bodyweights without negatively impacting reproductive success. Results from this study indicate pregnancy rates of heifers developed on a low-plane stair-step program did not differ from those developed on the same diet at higher planes of nutrition. In addition, management of diet utilization through the use of stair-step development programs is effective at decreasing overall cost per pregnancy. Limiting intake allowed for increased extent of digestion of the diet resulting in greater than predicted growth rates of heifers during the feeding period allowing them to reach reproductive maturity by the start of the breeding season. Further research should be conducted to accurately determine the treatment effects on pregnancy and lifetime performance of heifers and their calves.

A decision tool was developed to aid managers in selecting from five different heifer development program based on an operations unique inputs with the goal of reducing potential error associated with a heuristic decision strategy. Through a sensitivity analysis it was observed that calf prices had the greatest impact on overall decision outcomes and thus should be considered an important factor to take into consideration when selecting a development program. Future improvement of the decision tool should include a component accounting for NPV of the developed heifers as the lasting implications of a development program decision were not completely accounted for.

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APPENDIX A

CHAPTER I FIGURES

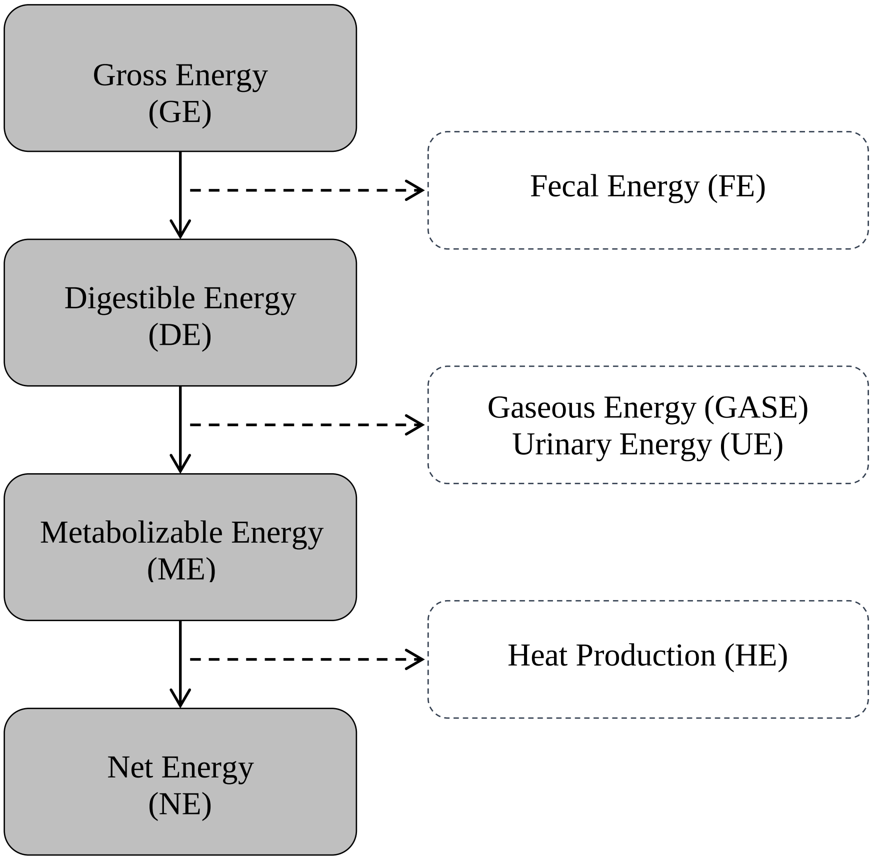


Figure A1. Outline of energy partitioning in beef cattle. Adapted and reprinted from NASEM, 2016.

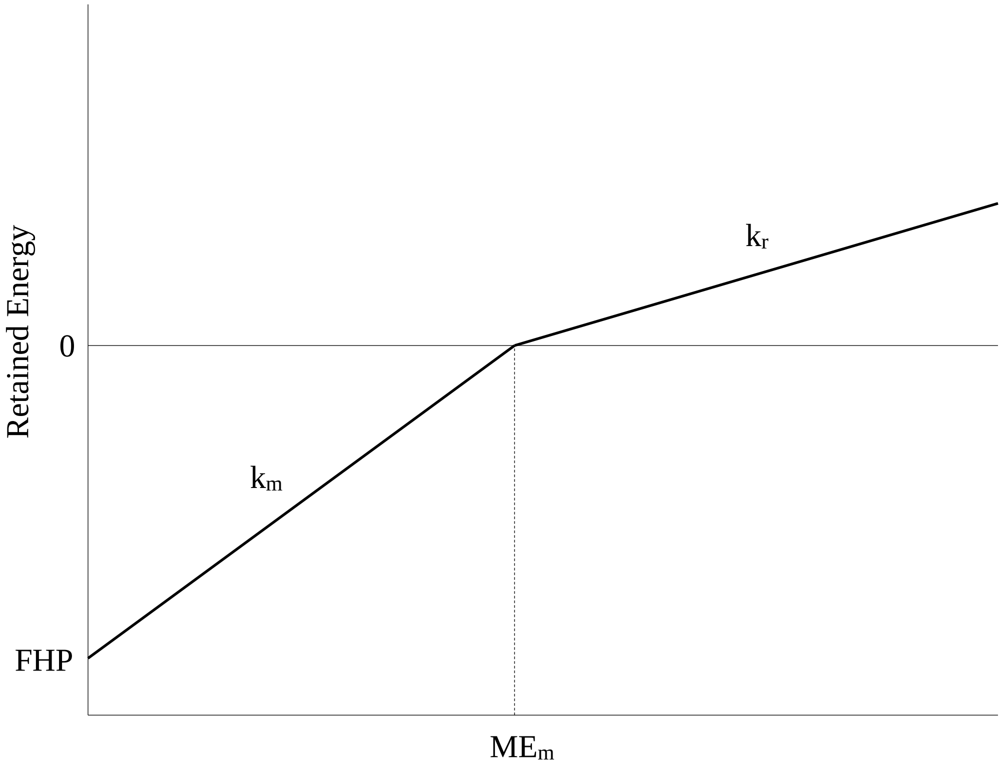


Figure A2. Partial efficiency of ME utilization for maintenance and growth. Reprinted from Garrett and Johnson, 1983.

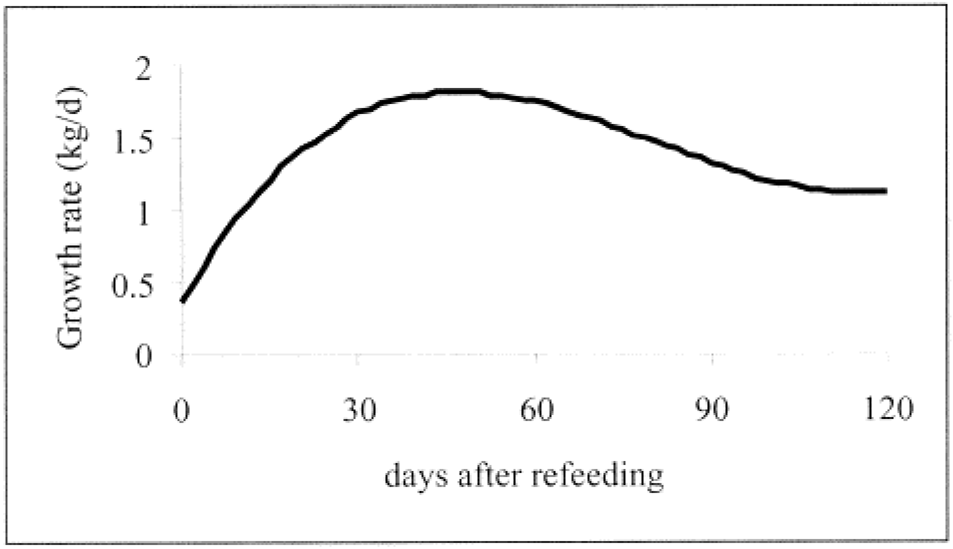


Figure A3. Evolution of the average daily gain during compensatory growth in cattle. Reprinted from Hornick et al., 2000.

APPENDIX B

CHAPTER II TABLES AND FIGURES

Tables

Table B1. Ingredient and nutrient composition of diet

Item	
Ingredient[1]	*% of diet*
Corn – cracked	42
Dried distillers' grains	26
Alfalfa hay	26
Molasses	6
Component	
DM basis	
OM, %	93.8
ADF, %	23.6
CP, %	14.0
TDN, %	73.7
Energy	
GE, Mcal/kg	3.92
NE_m, Mcal/kg	1.94
NE_g, Mcal/kg	1.11

[1] Rumensin pre-mix top dressed daily; approximately 100 mg monensin/hd/d.

Table B2. Intake and diet digestion for heifers developed on three different levels of stair-step nutrition programs

Item	Treatment[1] H	Treatment[1] M	Treatment[1] L	SEM[2]	Probability Trt
Phase 1					
DM intake, kg/d	4.38^{a}	3.56^{b}	2.61^{c}	0.17	<0.01
Energy Intake, Mcal/d					
GE	16.45^{a}	13.38^{b}	9.82^{c}	0.63	<0.01
DE	13.95^{a}	11.50^{b}	8.61^{c}	0.55	<0.01
Digestion, %					
DM	86.2^{a}	87.5^{ab}	88.7^{b}	0.68	0.04
OM	86.9^{a}	88.2^{ab}	89.4^{b}	0.66	0.04
ADF	64.0^{a}	66.6^{ab}	70.3^{b}	1.67	0.04
Increase in DM intake, kg/d[3]	2.66^{a}	3.06^{b}	3.41^{c}	0.03	<0.01
Phase 2					
DM intake, kg/d	6.59^{a}	6.34^{a}	5.89^{b}	0.15	0.01
Energy Intake, Mcal/d					
GE	27.01^{a}	25.99^{a}	24.14^{b}	0.62	0.01
DE	21.66^{a}	20.46^{a}	18.28^{b}	0.67	<0.01
Digestion, %					
DM	80.7	79.3	76.4	1.77	0.23
OM	81.6	80.3	77.3	1.77	0.23
ADF	58.9	55.2	55.2	2.65	0.54

[1] Treatments represent programmed rates of gain. P1: H = high, 0.92 kg/d; M = medium, 0.45 kg/d; L = low, 0.00 kg/d; all heifers programmed to gain 1.36 kg/d in P2.

[2] Pooled standard error of least squares means (high *n* = 29; medium *n* = 28; low *n* = 28)

[3] Increase in DM intake from phase 1 to phase 2

[a,b,c] Within a row, means without a common superscript differ ($P < 0.05$).

Table B3. Average daily gain and cost[3] of development for heifers developed on three different levels of stair-step nutrition programs

	Treatment[1]				Probability
Item	H	M	L	SEM[2]	Trt
ADG d -93 to d 0[3]	-0.20	-0.28	-0.24	0.05	0.59
Phase 1					
ADG, kg/d	0.83^a	0.61^b	0.37^c	0.03	<0.01
Cost of development[4], $/hd	36.08^a	29.35^b	21.88^c	0.52	<0.01
Phase 2					
ADG, kg/d	1.31	1.41	1.37	0.03	0.07
Cost of development[4], $/hd	59.27^a	55.54^b	50.54^c	0.76	<0.01
Total[5]					
ADG, kg/d	1.06^a	1.00^a	0.85^b	0.02	<0.01
Cost of development[4], $/hd	95.35^a	84.89^b	72.41^c	1.27	<0.01

[1] Treatments represent programmed rates of gain. Phase 1: H = high, 0.92 kg/d; M = medium, 0.45 kg/d; L = low, 0.00 kg/d; all heifers programmed to gain 1.36 kg/d in phase 2.

[2] Pooled standard error of least squares means (high n = 29 ; medium n = 28; low n = 28)

[3] ADG from weaning (d -93) to start of treatment (d 0)

[4] Cost of development determined using feed costs only, all other costs were considered constant between treatments

[5] Total ADG and cost of development are for phase 1 and phase 2 only.

[a,b,c] Within a row, means without a common superscript differ ($P < 0.05$).

Table B4. Body weight measurements of heifers from weaning to pregnancy determination developed on three different levels of stair-step nutrition programs

	Treatment[1]				Probability
Item	H	M	L	SEM[2]	Trt
BW,kg					
Weaning[3]	233	236	232	4.1	0.72
d 0	207	210	209	5.1	0.78
d 49	247^{a}	241^{a}	227^{b}	6.5	0.01
d 90	307	309	294	7.2	0.10
d 126	317	319	311	4.9	0.43
d 154	341	345	334	4.7	0.24

[1] Treatments represent programmed rates of gain. Phase 1: H = high, 0.92 kg/d; M = medium, 0.45 kg/d; L = low, 0.00 kg/d; all heifers programmed to gain 1.36 kg/d in phase 2.

[2] Pooled standard error of least squares means (high $n = 29$; medium $n = 28$; low $n = 28$)

[3] Weaning occurred, on average, 93d prior to starting the trial

[a,b] Within a row, means without a common superscript differ ($P < 0.05$).

Table B5. Percent heifers pubertal on three different levels of stair-step nutrition programs

	Treatment[1]				Probability
Item	H	M	L	SEM[2]	Trt
Pubertal, %					
d 0	0.00	3.51	0.00	4.00	0.99
d 28	3.45	3.51	3.51	4.00	0.99
d 56	10.34	7.24	10.71	7.00	0.65
d 90	51.72	46.43	32.14	9.00	0.32

[1] Treatments represent programmed rates of gain. Phase 1: H = high, 0.92 kg/d; M = medium, 0.45 kg/d; L = low, 0.00 kg/d; all heifers programmed to gain 1.36 kg/d in phase 2.

Table B6. Pregnancy rates of heifers fed on three different levels of stair-step nutrition programs and subsequent cost per pregnancy

	Treatment[1]				Probability
Item	H	M	L	SEM[2]	Trt
Pregnant, %					
d 126	44.83	57.14	40.74	10.0	0.45
d 154	79.31	96.43	82.14	8.0	0.21
d 260	96.55	100.00	96.43	3.5	0.99
Feed cost per pregnancy, $/hd					
d 154	120.23^{a}	88.04^{b}	88.16^{b}	1.49	<0.01
d 260	98.76^{a}	84.89^{b}	75.10^{c}	1.30	<0.01

[1] Treatments represent programmed rates of gain. P1: H = high, 0.92 kg/d; M = medium, 0.45 kg/d; L = low, 0.00 kg/d; all heifers programmed to gain 1.36 kg/d in P2.

[a,b] Within a row, means without a common superscript differ ($P < 0.01$).

Figure

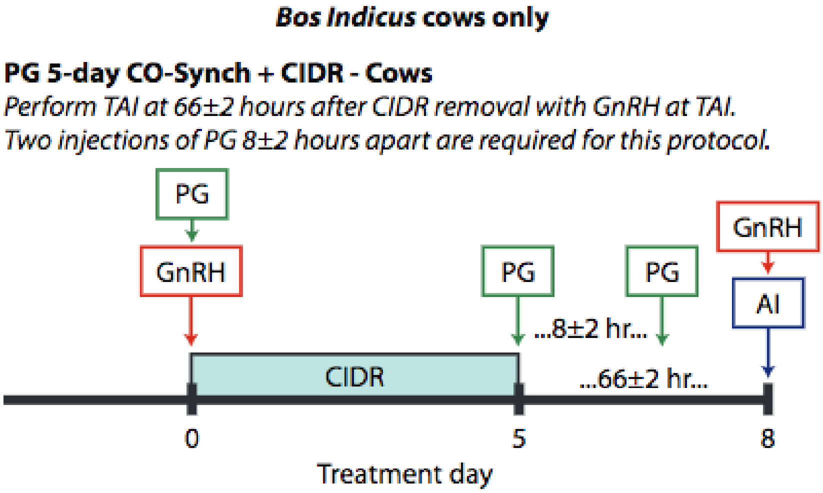


Figure B1. Fixed-time AI protocol for *Bos indicus*, PG 5-day CO-Synch + CIDR protocol. Reprinted from Johnson et al., 2016.

APPENDIX C

CHAPTER III TABLES AND FIGURES

Tables

Table C1. Ingredient and nutrient composition of diet utilized to develop heifers on five different development programs

Item	
Ingredient[1]	*% of diet*
Corn – cracked	42
Dried distillers' grains	26
Alfalfa hay	26
Molasses	6
Component	
DM basis	
OM, %	93.8
ADF, %	23.6
CP, %	14.0
TDN, %	73.7
Energy	
GE, Mcal/kg	3.92
NE_m, Mcal/kg	1.94
NE_g, Mcal/kg	1.11

[1] Rumensin pre-mix top dressed daily; approximately 100 mg monensin/hd/d

Table C2. Management decision inputs used to calculate cost per pregnancy for five different heifer development programs

Item	
Number of cows in herd[1]	1000
Replacement rate, %[1]	15.0
Number of females to replace[2]	150
Other losses, %[1]	2.0
Average WW, lb[3]	515
Weaned calf price, $/cwt[1,4]	155.00
Weaned calf value, $[5]	798.25
Yearling heifer price, $/cwt[1,4]	135.00
Yardage cost, $/hd/d[1,4]	0.38
Pasture lease cost, $/hd/d[1,4]	0.50
Cost of ionophore, $/hd/d[1,4]	0.03
Ration cost, $/ton[1,4]	140.0

[1] Values can be modified to reflect specific operations

[2] Calculated value based on number of cows in the herd and the desired replacement rate

[3] Set value based on previous experiment values (Chapter II)

[4] Prices set based on current market values

[5] Calculated value based on average WW and weaned calf price.

Table C3. Decision tool assumptions made to calculate cost per pregnancy for five different heifer development programs

Item[1]	
Breed type	Cross-bred *Bos indicus*
Synchronization	Yes
AI	Yes
Weaning age, mo	8
Weaning weight, lb	515
Breeding age, mo	14
Breeding season, d	60
Mature BW, lb	1100

[1] All assumptions were based on previous experiment values (Chapter II).

Table C4. High and low pregnancy rates used for five heifer development programs

Item	
Development program	*Pregnancy rate, %*
Constant-gain, 62% MW[1]	
High	91
Low	85
Constant-gain, 55% MW[1]	
High	88
Low	84
High-plane stair-step[2]	
High	84
Low	76
Medium-plane stair-step[2]	
High	98
Low	94
Low-plane stair-step[2]	
High	86
Low	78

[1] Pregnancy rates adapted from Lardner et al., 2014. High and low pregnancy rates represent the optimum and conservative expected rates for a given program, respectively.

[2] Pregnancy rates adapted from previous experiment (Chapter II). High and low pregnancy rates represent the optimum and conservative expected rates for a given program, respectively. Pregnancy rates were adjusted based on previously reported standard error values to obtain a high and low rate (Patterson et al., 1992; Lardner et al., 2014).

Table C5. Partial budget of five different heifer development programs

Item[3]	Development program 62% MW[1]	 55% MW[1]	 H[2]	 M[2]	 L[2]
Expense					
Opportunity cost, $[4]	138201.44	142088.73	152864.88	127720.00	149272.75
Pasture and yardage, $/hd[5]	68.40	68.40	79.20	79.20	79.20
Total feed costs, $/hd[6]	128.16	105.48	85.32	76.03	64.55
Total development costs, $[7]	34201.44	30950.64	31505.77	24837.12	26881.62
Revenue					
Revenue from culls, $[8]	23352.79	25174.42	40988.73	7444.98	34932.98
Cost per pregnancy, $[9]	979.11	966.44	938.24	945.11	923.13

[1] Development programs represent constant gain strategies with target end weights of 62 or 55% MW.

[2] Development programs represent varying levels of nutrition for 3 different levels of stair-step development; H = high, M = medium, L = low.

[3] Decision tool outputs were calculated using inputs shown in Tables C2 and C3. Average pregnancy rates (Table C4) were used for each treatment, thus outputs represent average values for heifers retained, cull revenue, and CPP.

[4] Opportunity costs represent the revenue that would have been realized had all heifers retained for development been sold at weaning.

[5] Pasture and yardage represent the cost accrued for each heifer during the development period.

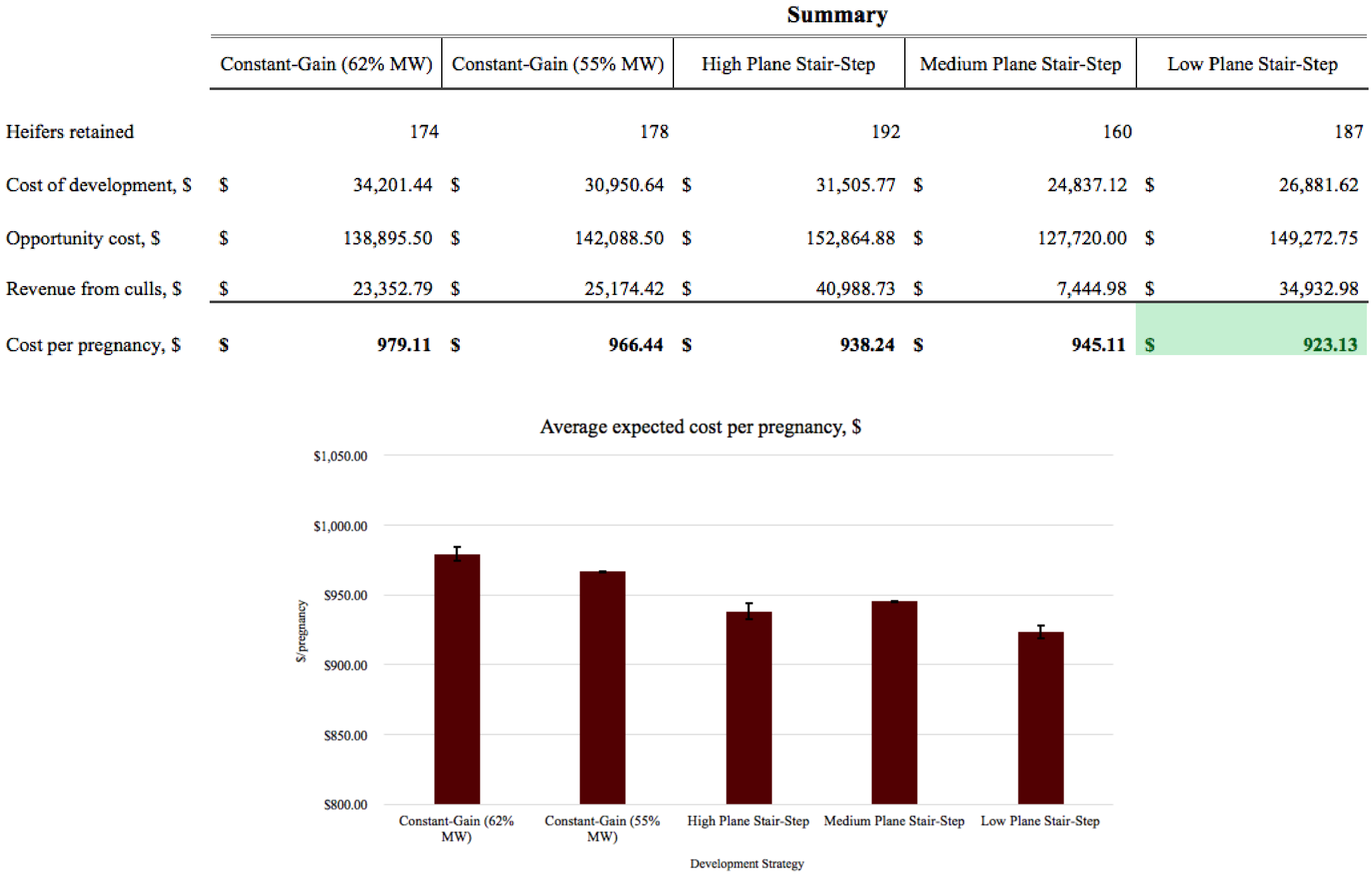
[6] Total feed costs include ration and ionophore cost for the entirety of development for each heifer.

[7] Total development costs represent the sum of total feed, pasture, and yardage costs for all retained heifers.

[8] Revenue from culls represents the return revenue for those heifers that are expected to be open at the end of the breeding season.

[9] Cost per pregnancy is the sum of total development and opportunity costs less cull revenue, divided by the numbers of heifers bred.

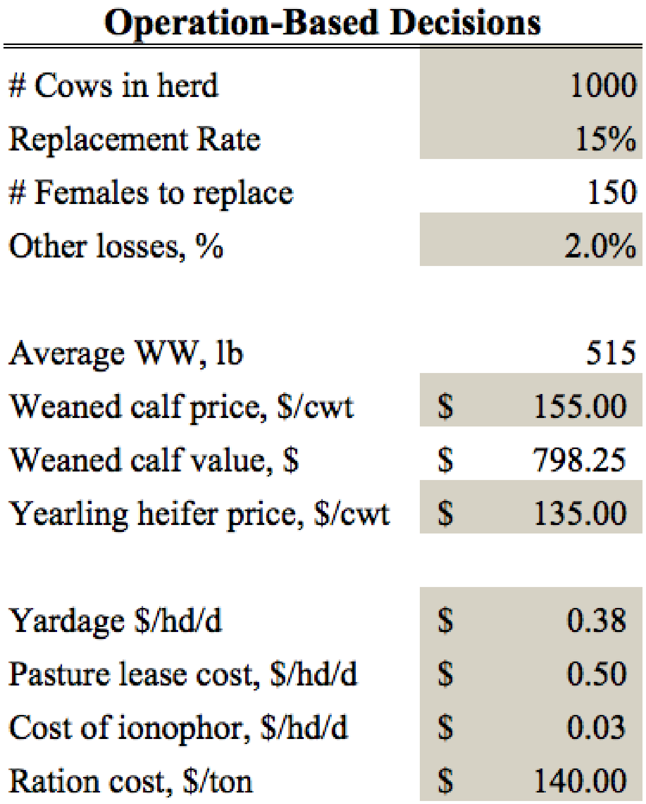
Figures



Summary

	Constant-Gain (62% MW)	Constant-Gain (55% MW)	High Plane Stair-Step	Medium Plane Stair-Step	Low Plane Stair-Step
Heifers retained	174	178	192	160	187
Cost of development, $	$ 34,201.44	$ 30,950.64	$ 31,505.77	$ 24,837.12	$ 26,881.62
Opportunity cost, $	$ 138,895.50	$ 142,088.50	$ 152,864.88	$ 127,720.00	$ 149,272.75
Revenue from culls, $	$ 23,352.79	$ 25,174.42	$ 40,988.73	$ 7,444.98	$ 34,932.98
Cost per pregnancy, $	**$ 979.11**	**$ 966.44**	**$ 938.24**	**$ 945.11**	**$ 923.13**

Figure C1. Screenshot of decision tool “dashboard” with inputs from Table C2.



Operation-Based Decisions

# Cows in herd		1000
Replacement Rate		15%
# Females to replace		150
Other losses, %		2.0%
Average WW, lb		515
Weaned calf price, $/cwt	$	155.00
Weaned calf value, $	$	798.25
Yearling heifer price, $/cwt	$	135.00
Yardage $/hd/d	$	0.38
Pasture lease cost, $/hd/d	$	0.50
Cost of ionophor, $/hd/d	$	0.03
Ration cost, $/ton	$	140.00

Figure C2. Screenshot of operation-based decisions page; highlighted cells can be modified.

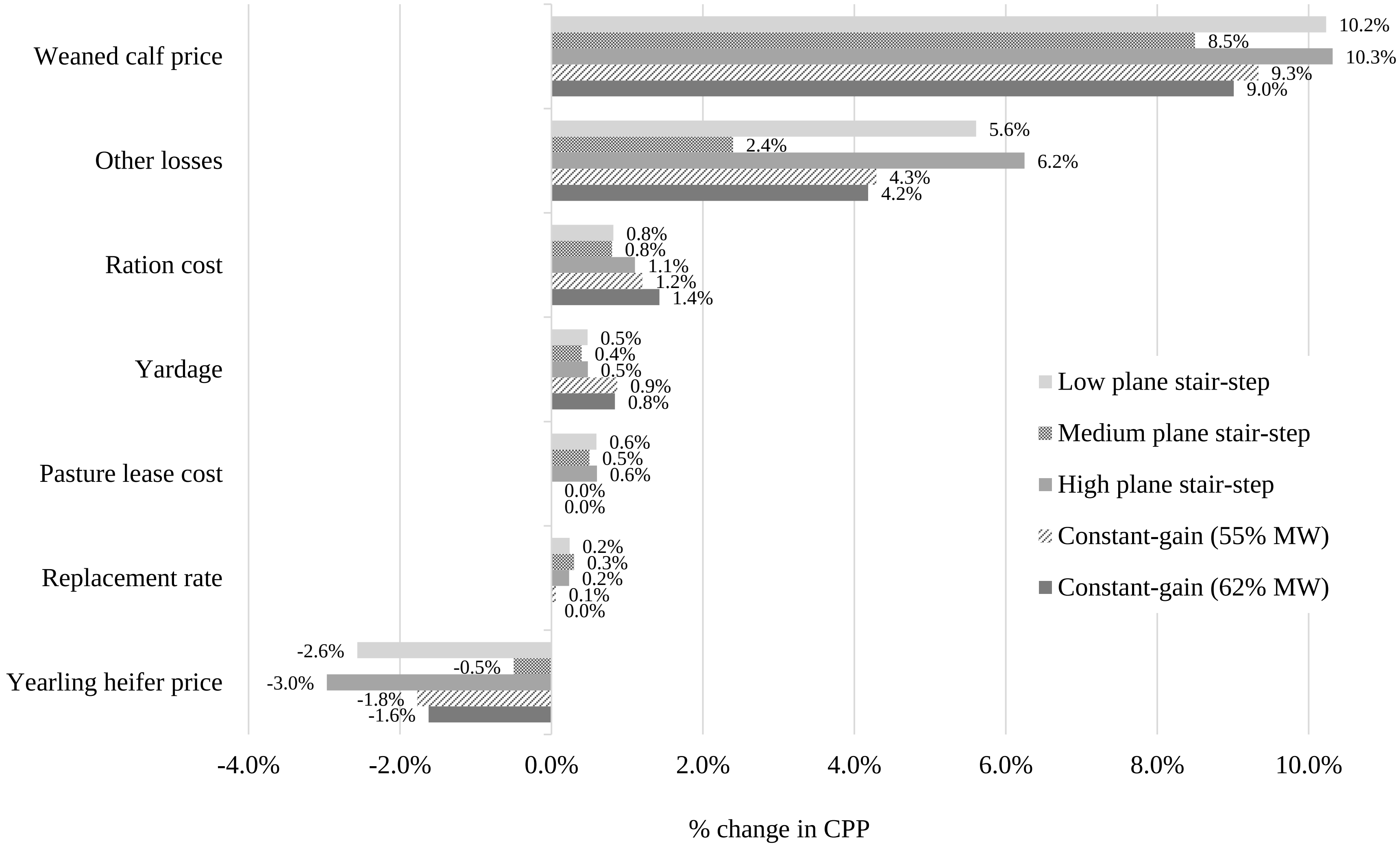
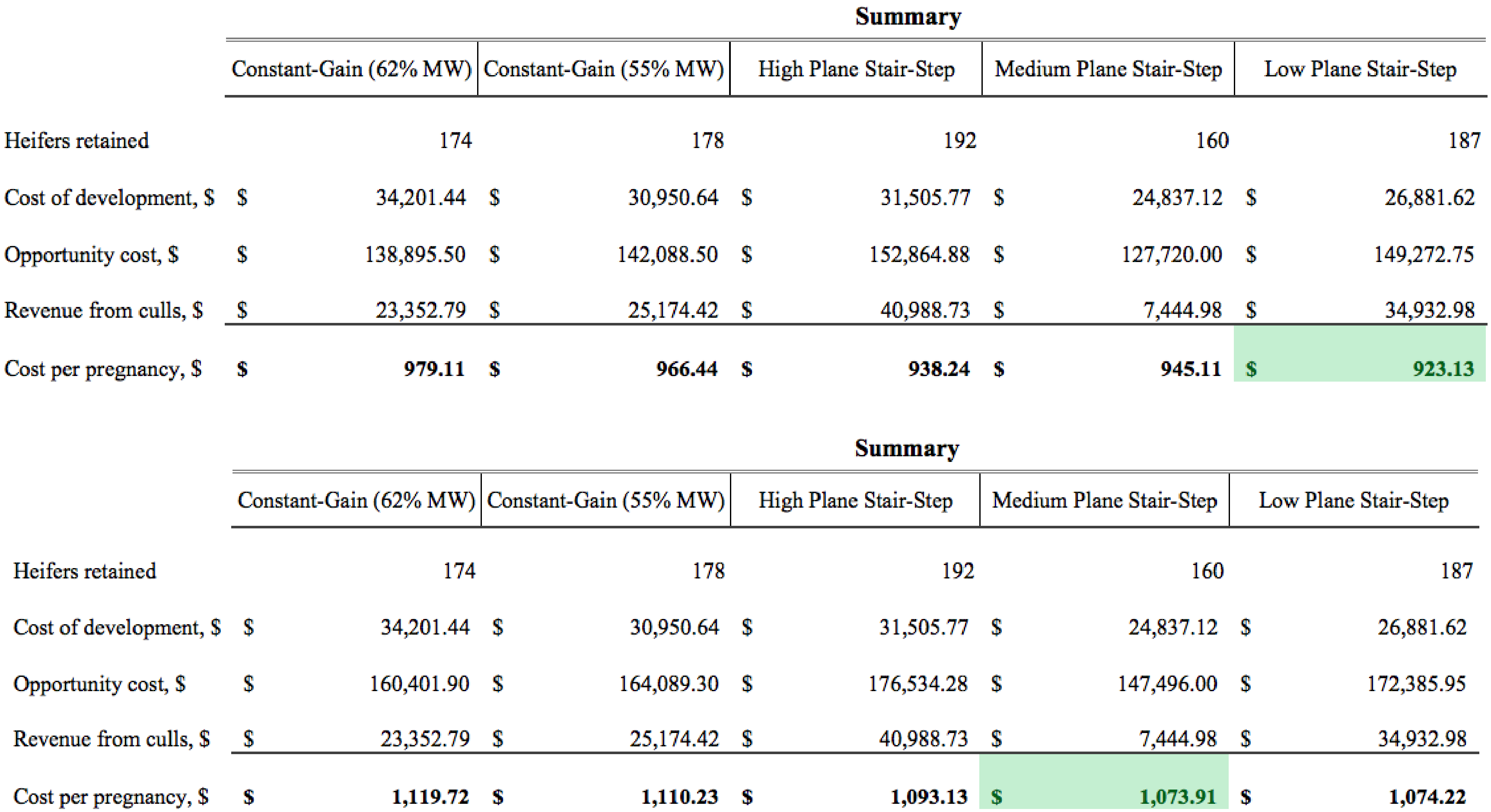


Figure C3. Effect of 10% increase in a single variable on % change in cost per pregnancy (CPP) for five development programs.



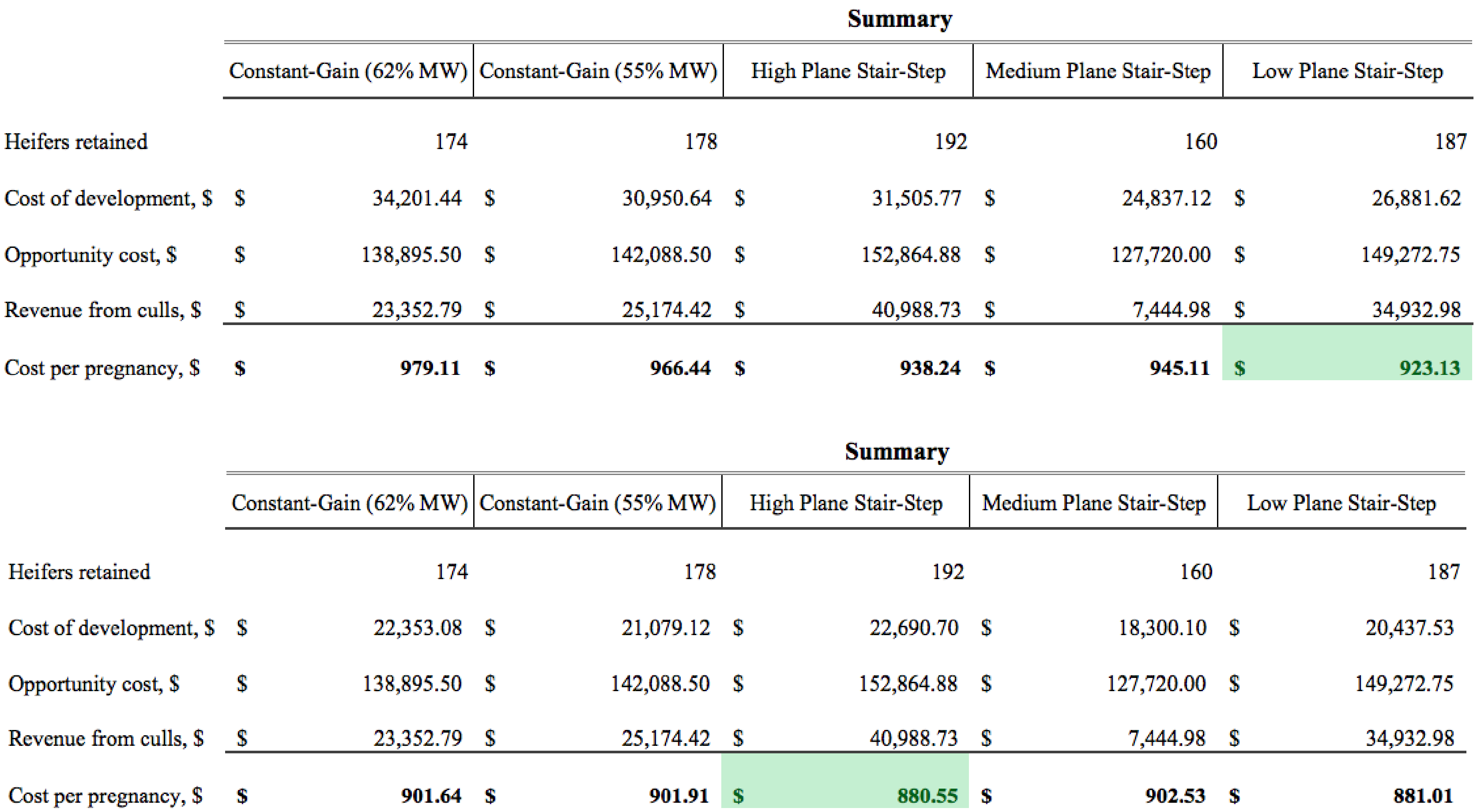
Summary

	Constant-Gain (62% MW)	Constant-Gain (55% MW)	High Plane Stair-Step	Medium Plane Stair-Step	Low Plane Stair-Step
Heifers retained	174	178	192	160	187
Cost of development, $	$ 34,201.44	$ 30,950.64	$ 31,505.77	$ 24,837.12	$ 26,881.62
Opportunity cost, $	$ 138,895.50	$ 142,088.50	$ 152,864.88	$ 127,720.00	$ 149,272.75
Revenue from culls, $	$ 23,352.79	$ 25,174.42	$ 40,988.73	$ 7,444.98	$ 34,932.98
Cost per pregnancy, $	**$ 979.11**	**$ 966.44**	**$ 938.24**	**$ 945.11**	**$ 923.13**

Summary

	Constant-Gain (62% MW)	Constant-Gain (55% MW)	High Plane Stair-Step	Medium Plane Stair-Step	Low Plane Stair-Step
Heifers retained	174	178	192	160	187
Cost of development, $	$ 34,201.44	$ 30,950.64	$ 31,505.77	$ 24,837.12	$ 26,881.62
Opportunity cost, $	$ 160,401.90	$ 164,089.30	$ 176,534.28	$ 147,496.00	$ 172,385.95
Revenue from culls, $	$ 23,352.79	$ 25,174.42	$ 40,988.73	$ 7,444.98	$ 34,932.98
Cost per pregnancy, $	**$ 1,119.72**	**$ 1,110.23**	**$ 1,093.13**	**$ 1,073.91**	**$ 1,074.22**

Figure C4. Resulting effect of 15% increase in weaned calf price on CPP represented by second output.



Summary

	Constant-Gain (62% MW)	Constant-Gain (55% MW)	High Plane Stair-Step	Medium Plane Stair-Step	Low Plane Stair-Step
Heifers retained	174	178	192	160	187
Cost of development, $	$ 34,201.44	$ 30,950.64	$ 31,505.77	$ 24,837.12	$ 26,881.62
Opportunity cost, $	$ 138,895.50	$ 142,088.50	$ 152,864.88	$ 127,720.00	$ 149,272.75
Revenue from culls, $	$ 23,352.79	$ 25,174.42	$ 40,988.73	$ 7,444.98	$ 34,932.98
Cost per pregnancy, $	**$ 979.11**	**$ 966.44**	**$ 938.24**	**$ 945.11**	**$ 923.13**

Summary

	Constant-Gain (62% MW)	Constant-Gain (55% MW)	High Plane Stair-Step	Medium Plane Stair-Step	Low Plane Stair-Step
Heifers retained	174	178	192	160	187
Cost of development, $	$ 22,353.08	$ 21,079.12	$ 22,690.70	$ 18,300.10	$ 20,437.53
Opportunity cost, $	$ 138,895.50	$ 142,088.50	$ 152,864.88	$ 127,720.00	$ 149,272.75
Revenue from culls, $	$ 23,352.79	$ 25,174.42	$ 40,988.73	$ 7,444.98	$ 34,932.98
Cost per pregnancy, $	**$ 901.64**	**$ 901.91**	**$ 880.55**	**$ 902.53**	**$ 881.01**

Figure C5. Resulting effect of 56% increase in feed cost on CPP represented by second output.